The Global Weather Experiment — Final Report of U.S. Operations

Rockville, Md.
April 1981

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Research and Development

OVERVIEW OF THE GLOBAL WEATHER EXPERIMENT

The Global Weather Experiment was the largest international scientific experiment ever attempted.

WHEN	Build-up Year	1 December 1977 to 30 November 1978
	Operational Year	1 December 1978 to 30 November 1979
	Special Observing Periods	5 January to 5 March 1979
		1 May to 30 June 1979

The research phase actively began in 1979 and will continue for a decade.

WHO Over 140 countries contributed to the Global Weather Experiment through the World Weather Watch. Of these, 70 countries and 5 international organizations made special contributions to the Global Weather Experiment and the associated regional experiments. Total international participation included over 5000 individuals.

HOW OBSERVING SYSTEMS

WORLD WEATHER WATCH: Surface network, upper air network, special stations, temporarily upgraded island stations.

GEOSTATIONARY SATELLITES: GMS (Japan) 140°E; GOES-West (USA) 135°W; GOES-East (USA) 75°W; METEOSAT (ESA) 0°; GOES Indian Ocean (USA) 58°E.

POLAR ORBITING SATELLITES: NOAA-5; TIROS-N; NOAA-6; NIMBUS-7.

DRIFTING BUOYS: 319 in the Southern Hemisphere; 28 oceanographic drifters in the Tropics; 27 drifting ice buoys in the Polar Regions.

TROPICAL CONSTANT LEVEL BALLOONS: 313 platforms and approximately 50,000 wind and temperature observations.

AIRCRAFT DROPWINDSONDE SYSTEMS: U.S. Air Force C-141's in the Pacific and the Atlantic; U.S. Air Force C-135's in the Atlantic; NOAA P-3's and C-130 in the Indian Ocean. Nine aircraft and 5,000 wind and thermodynamic soundings.

TROPICAL WIND OBSERVING SHIPS: SOP-I: 40 ships; SOP-II: 43 ships.

AUTOMATED AIRCRAFT FLIGHT LEVEL SYSTEMS: 80 Aircraft Integrated Data Systems (AIDS); 17 Aircraft to Satellite Data Relay Systems (ASDAR); 11 ACARS/MOAT systems (ARINC Communications Addressing and Reporting System/Meteorological Optional Auxiliary Terminal).

OTHER OBSERVING SYSTEMS: The regional experiments associated with the Global Weather Experiment are the Winter and Summer Monsoon Experiments (MONEX); the West African Monsoon Experiment (WAMEX); and the Polar Experiment (POLEX). There were also related oceanographic experiments being carried out in the Tropical Oceans.

DATA MANAGEMENT: 26 Data Management Centers worldwide

COST The estimated international financial resources for the Global Weather Experiment are between $300 and $500 million, depending upon how one allocates the satellite costs between FGGE operations and normal operations. Similar uncertainty exists for the U.S. costs, but the total is approximately $200 million or approximately $1.00 for every U.S. citizen.

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U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
James P Walsh, Acting Administrator

Office of Research and Development
Ferris Webster, Assistant Administrator

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PREFACE

From the beginning of December 1978 through November 1979, the highest concentration of scientific resources ever assembled was brought to bear on the challenge of observing the Earth's atmosphere and oceans. This activity involved the efforts of over 140 countries and was called the Global Weather Experiment, the largest international scientific experiment yet attempted.

The origin of this international effort occurred 18 years earlier when President John F. Kennedy gave his 1961 address to the United Nations General Assembly calling for international cooperation in the environment. This speech ignited a sequence of events leading to the unique 1967 agreement between an intergovernmental body, the World Meteorological Organization of the United Nations, and a non-governmental body, the International Council of Scientific Unions, to sponsor jointly the Global Atmospheric Research Program (GARP). From the beginning of GARP, it was understood that an extended global observing program was needed, and after more than 10 years of planning, the First GARP Global Experiment (FGGE), also called the Global Weather Experiment, became a reality.

It was originally thought that a composite observing system of satellites, aircrafts, ships, drifting buoys, balloons and other special systems augmenting the conventional surface and upper-air observations would monitor the entire global atmosphere for a full year. However, primarily due to the high operating costs of aircraft and ships, the final design of the Global Weather Experiment confined operations of some systems to two Special Observing Periods within the Operational Year. Following the field phase and data management phase, a multi-year evaluation and research program began. It will continue until the late 1980s.

An explicit statement of the goals of the Global Weather Experiment can be found in several GARP publications (a complete bibliography of related documents can be found at the end of this volume). These goals can be briefly summarized in layman's terms: (i) to improve our understanding of atmospheric dynamics and the general circulation of the atmosphere, and hence improve our ability to model those mechanisms responsible for that circulation; (ii) to determine the theoretical and practical limits of atmospheric predictability; (iii) to design an optimal, affordable observing system for the future; (iv) to improve models of climate change by fully and accurately simulating the annual cycle as observed over FGGE's Operational Year. Achieving these goals will require the zealous efforts and creative talents of the research community.

Early indications are that the seeds sown in this international effort will reap a rich harvest of results -- meeting the aforementioned goals serving as a fountainhead for fresh ideas, and stimulating new thrusts across a spectrum of atmospheric research topics and applications. These early results have already appeared in published reports and scientific periodicals and are not repeated in this volume.

This brings me to the purpose of the unique collection of papers which comprise this report. The manuscripts in this set describe the field events during the Experiment and review the complex operations through the eyes of those who were present. They are meant to complement those many planning

documents prepared before the Experiment and the scientific results which have been or will be published after the Experiment. This volume, with the above mentioned literature, thus attempts to complete a proper historical perspective of the Experiment as a whole.

Another purpose of this document is to aid in the planning and implementation of future large scale experiments. The authored papers contained herein describe operational experiences with the various United States observing systems. In view of the fact that the United States contributed substantially to each of the major types of observing systems, this provides a reasonably comprehensive guide to the international experience as a whole. In describing the observing system operations, authors were asked to provide a brief review of system objectives, data extraction techniques, notable successes, difficulties encountered and fixes required, along with recommendations for future experiments. A wealth of material and detail has been provided. We hope it will serve as a useful reference.

Chapter 1 is a discussion of the United States FGGE Coordinating Center, a critical component to an experiment of this magnitude. Chapters 2 and 3 describe the United States polar orbiting and geostationary satellite operations. The Experiment, including the associated Regional Experiments (the Monsoon Experiment, the West African Monsoon Experiment and the Polar Experiment), was fortunate to have all of the originally planned five geostationary satellites operating for the FGGE year. This was the first and only year of such coverage. There are currently only three of these satellites operational; the European Space Agency satellite failed just four days before the year-long Experiment ended and the spare United States satellite temporarily placed over the Indian Ocean for the Experiment has since been returned to its pre-Experiment location. A special note of praise is due those agencies in the United States (NASA, NOAA and NSF) and in Europe (European Space Agency) for their rapid response in filling the unexpected eleventh hour gap in the Indian Ocean satellite coverage.

Chapters 4 and 5 describe United States buoy and constant level balloon operations. These systems communicated their data through the new United States third generation polar orbiting satellite system, TIROS-N. These three systems together made substantial contributions to the Experiment. The drifting buoys gave us a new perception of the number and intensity of Southern Hemisphere storm systems; the constant level balloons provided over 50,000 upper tropospheric wind vectors in the tropics; TIROS-N supplied improved temperature soundings globally (see Chapter 2), and the French-built communication system on-board was indispensable to the success of the Experiment. Consequently, the last minute launch of the satellite just prior to the Experiment provided an extra level of excitement.

Chapters 6 and 7 discuss the Aircraft Dropwindsonde System deployed in the tropics. The United States had agreed to assume the lion's share of the difficult challenge of observing the three dimensional structure of the tropical wind field. United States Air Force and NOAA research aircraft flew missions over all three tropical oceans covering a combined area of approximately 10 million square miles each day. Complementing the aircraft were the Tropical Wind Observing Ships. The United States contribution to this system is discussed in Chapter 8.

Chapters 9 and 10 describe United States efforts to augment the World Weather Watch during the Experiment. These include: the implementation of a new real-time automated observing system for wide-bodied commercial aircraft (ASDAR), a similar automated record-only system (AIDS), and special efforts to both upgrade and add new land-based upper-air observations in the tropics. Chapter 11 reveals the United States Data Management operations, which were an integral part of the complex international data management plan.

In addition to operational and special data collection efforts, several important data sets were provided by NASA's NIMBUS-7 research satellite. While these were planned as part of the Experiment, the operation of the satellite system was primarily independent and specific discussion of it is not included here. United States contributions to the Monsoon Experiment (MONEX) and the Polar Experiment (POLEX), which were regional experiments associated with the Global Weather Experiment, are also not included here. The planning for these activities was fully coordinated with the United States FGGE Project Office, but the successful operations of their respective observing systems were for the most part independent (e.g., there was a separate MONEX Project Office responsible for the United States contributions to MONEX, and the operation of the United States drifting ice buoys program in the Arctic was conducted by the University of Washington). FGGE oceanographic activities were primarily planned and implemented by individual scientists and are not reported here. Finally, there was another real-time aircraft system operated by American Airlines, producing data similar to ASDAR and AIDS, which provided relevant error statistics of winds and temperatures over the continental United States. This program was not an official part of the Experiment and is not discussed in this report.

This Experiment represents only a brief episode in the evolution of atmospheric research. However, it was carefully constructed on the foundation of our previous knowledge, and I believe that it will be viewed as a memorable milestone in atmospheric science. Let us hope that history also looks favorably upon the actions of the nations of the world immediately after the Global Weather Experiment -- that they used the Experiment as a signal for ever greater cooperation and as a pivotal milestone which launched a truly global operational atmospheric observing system.

A great many scientists, engineers and administrators from many countries contributed to the Global Weather Experiment planning and implementation through the years. Those agencies and organizations which funded and/or participated in the United States implementation are listed in the appendix. I do wish to thank the authors who contributed to this volume. Thanks are also due to Mr. William Murray for coordinating its preparation and for his help in editing; Ms. Tina Loughran for final assembly and graphics work; and Mrs. Betty Sonnefeld and Ms. Noreen Prather for their splendid typing.

Rex J. Fleming
Director
U.S. FGGE Project Office

CONTENTS

CHAPTER 1

U. S. FGGE COORDINATING CENTER

By
Mr. T. Kaneshige

(U. S. FGGE Project Office)

1. INTRODUCTION

The First GARP Global Experiment (FGGE) - the Global Weather Experiment, employed a complex array of observing systems and data management activities to produce the meteorological and oceanographic observations and initial state parameters required for FGGE research. Because of the global nature of the experiment, these activities were widely dispersed among a large number of nations and international organizations. To ensure the success of the experiment, an international FGGE Operations Center was established within the WMO Secretariat in Geneva, Switzerland, during the FGGE Operational Year.

The FGGE Operations Center relied heavily on the periodic status reports received from the various observing system and data management components to monitor the day-to-day status of the FGGE operations, and to assess (in a preliminary way) whether or not the FGGE objectives for observational coverage were being met. The U.S. FGGE Coordinating Center (US-FCC) served as the focus for all U.S. participation in the Observational Phase of the experiment and provided the necessary U.S. status reports to the international FGGE Operations Center. In addition, the US-FCC was also involved in some of the day-to-day planning and execution of U.S. field activities during the Special Observing Periods.

Descriptions of the FGGE observing systems and progress reports on the successes and failures of these systems during the first seven months of the Operational Year (December 1978-June 1979) were described in the articles by Fleming et al (1979a, 1979b).

This report describes the US-FCC and its planned activities, summarizes the results of the departures from the planned operations, highlights the difficulties encountered and the corresponding actions taken, and concludes with some statements on the overall success of the operations and on recommendations for coordinating future operational activities.

2. PURPOSE OF THE CENTER

The U.S. FGGE Coordinating Center was established to serve:

o <u>as the national focus for all U.S. FGGE operational activities</u> (tasks included monitoring the status of implementation and operations of all U.S. components; providing U.S. field units with operational, logistical, and administrative support as needed; and providing the Director of the U.S. FGGE Project Office with up-to-date information on the progress of U.S. operational activities.)

o <u>as the international focus for all U.S. FGGE activities</u> (tasks included providing the international FGGE Operations Center with periodic status reports on the operations of U.S. FGGE special observing systems and data management centers; serving as the focal point for ensuring that requests from the FGGE Operations Center for changes to U.S. FGGE operations plans were evaluated and implemented, if possible, and providing other international centers with pertinent information concerning the deployment and operations of certain U.S. platforms.)

o <u>as the source of operational guidance for certain U.S field units</u> during the FGGE Special Observing Periods (tasks included evaluating the

status of dropwindsonde aircraft and equipment; providing the anticipated weather along the flight tracks; transmitting messages to each aircraft operating location containing recommended tracks to be flown the following day; evaluating all pertinent information related to the spatial distribution and movement of tropical constant level balloon platforms; and transmitting advisories, as needed, to the balloon launch sites concerning balloon launch operations.)

3. DESCRIPTION OF THE CENTER AND ITS PLANNED ACTIVITIES

3.1 Organization of the Center

The US-FCC was organized under the U.S. FGGE Project Office, which provided or arranged resources needed to implement and operate the center. The center had direct access to international and national centers and activities, as shown in Figure 1.

3.2 Description of the Center

During the FGGE Operational Year (1 December 1978 to 30 November 1979), US-FCC operations were conducted for the most part during normal working hours (Monday-Friday, 0800-1630 Eastern Time) at the U.S. FGGE Project Office (FPO) in Rockville, Maryland. Staff members of the FPO and other NOAA headquarters components participated in the work of the center, since only a few individuals were directly assigned to the US-FCC.

During the two FGGE Special Observing Periods (SOPs), which extended from January 5 through March 5, 1979, and from May 1 through June 30, 1979, a special center was activated in the World Weather Building in Marlow Heights, Maryland, to enhance operational support of U.S. field activities and international monitoring and management activities. The center was located in a work area provided by the National Meteorological Center's Forecast Division, and US-FCC personnel were within easy reach of the National Meteorological Center, the National Environmental Satellite Service's (NESS) Satellite Analysis Branch, and the National Weather Service's (NWS) Communications Operating Branch. The center was manned 24 hours a day during the intensive periods of the SOPs, and during most of the daylight hours of the nonintensive periods of the SOPs. In addition to NOAA personnel, the National Center for Atmospheric Research provided a scientist, and the USAF Military Airlift Command and Air Weather Service provided aircraft, weather, and communications specialists to assist in the work of the US-FCC during the intensive periods of the SOPs.

The center had multiple communications links with the centers and activities shown in figure 1. These included commercial and U.S. military voice systems, the World Weather Watch Global Telecommunications System (GTS), commercial and U.S. military teletype networks, and a special National Aeronautics and Space Administration satellite link between the United States and Europe.

3.3 Planned Activities

During the intensive periods of the SOPs, primary consideration was given to supporting the daily aircraft dropwindsonde operations out of the four operating locations (OLs):

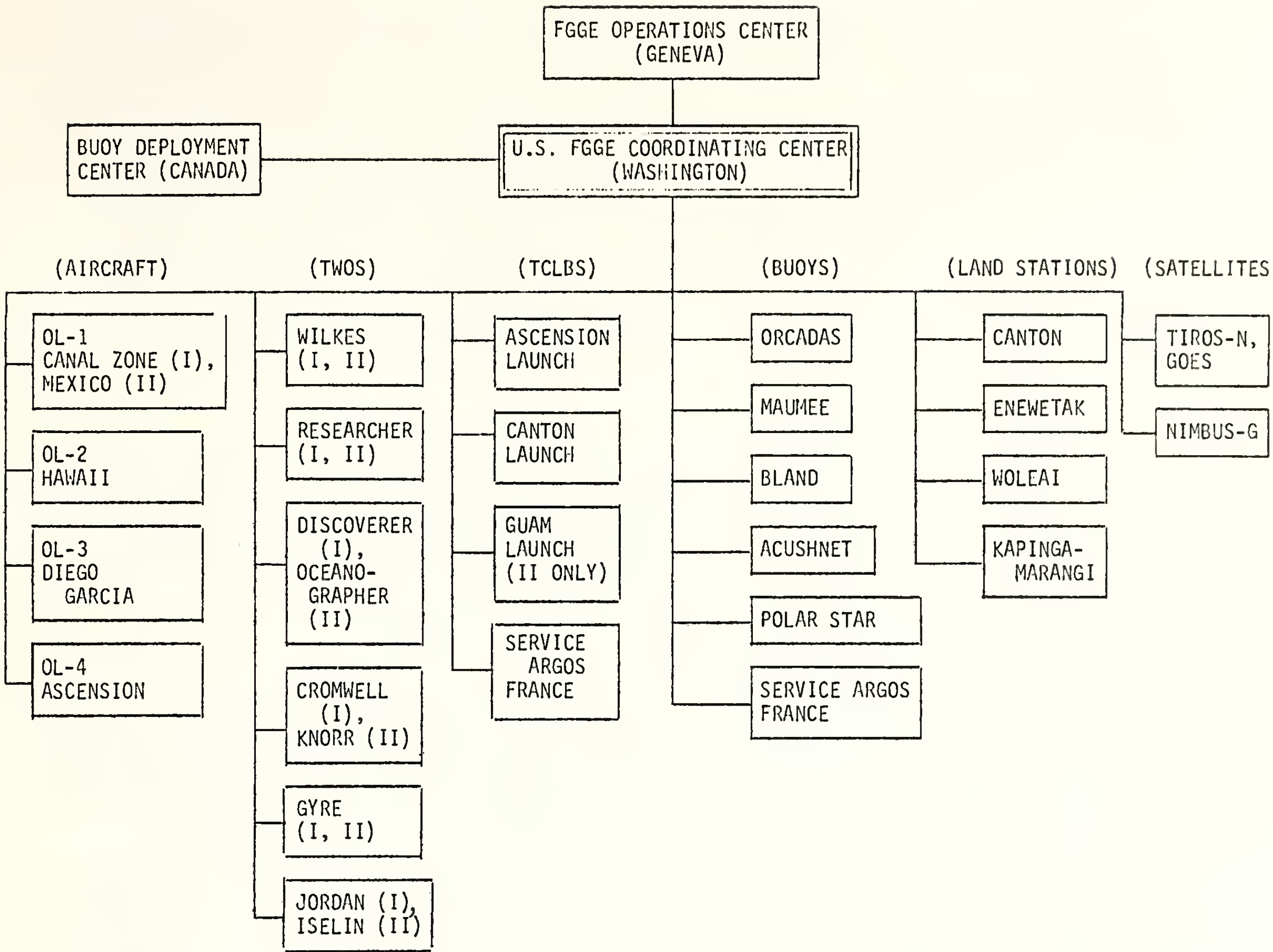

Figure 1.--Interfaces for U.S. FGGE Coordinating Center.

- o <u>OL1:</u> Howard AFB, Canal Zone (SOP-1); Acapulco, Mexico (SOP-2)
- o <u>OL2:</u> Hickam AFB, Hawaii
- o <u>OL3:</u> Diego Garcia
- o <u>OL4:</u> Ascension Island

This meant that both duty scientists and aircraft specialists were needed during the times of the day when the status of aircraft, equipment, expendables, and crew and the forecast weather conditions over the flight track areas had to be carefully evaluated prior to decisions on the flight tracks for the subsequent day's missions. Although the aircraft operated out of bases spread throughout most of the tropical belt, flight track selections for more than one operating location could be made at the same time because of the schedule of availability of certain guidance products. For this

system for communicating status reports from the island sites to the US-FCC was to use an HF radio link from the island sites to an appropriate Trust Territory District Center, where a teletype message was expected to be prepared and disseminated via teletype to the US-FCC. A few status reports were received at the US-FCC during the beginning of SOP-1, but severe problems with maintaining working generators at the observing sites resulted in the loss of some of the status reports. Since the 6th Weather Squadron (6WS) headquarters at Tinker AFB, Oklahoma was in frequent radio contact with its mobile upper air teams on Kapingamarangi and Woleai, the US-FCC decided to make an informal arrangement with the 6WS to obtain status information directly from the 6WS. This modified procedure provided most of the needed information.

4.2.2 Meteorological satellites

The coordination of satellite operations was very successful. Designated representatives of the National Environmental Satellite Service provided timely information by telephone on changes to the status of operational polar-orbiting and geostationary satellites.

4.2.3 Aircraft dropwindsonde program

The planned use of teletype and voice communications between the US-FCC and the aircraft operating locations to coordinate the FGGE dropwindsonde missions worked very well. Both incoming and outgoing messages (teletype and voice) were disseminated/received in a timely manner. When unusual problems occurred, the problems were discussed and solved over the telephone.

Weather forecast support from the NESS satellite meteorologists was good. Timely satellite photographs and film loops for the Pacific and Atlantic Ocean areas were available for the track selection decision making process. Available polar-orbiting satellite photographic products for the Indian Ocean area tended to be late or old, but the satellite meteorologists gave their best efforts to provide US-FCC scientists with "long-range" forecasts for the Indian Ocean flight track areas.

FGGE TWOS status information from the international FGGE Operations Center for the most part was available to the US-FCC. Some messages were unexplainably lost. Daily US-FCC outgoing aircraft dropwindsonde status reports to the FGGE Operations Center were disseminated routinely over the GTS without any difficulties.

4.2.4 Tropical constant level balloon system

The coordination of balloon platform launches was outstanding. The launch schedules were pre-planned but adjustments could be made if either the launch site or the US-FCC believed them to be necessary. On a few occasions when the weather at and around the Canton Island launch site was not favorable, launches were temporarily halted or slowed down until more favorable conditions occurred. In addition, when the circulation patterns at platform altitude were unfavorable, a similar halt or slowing down of the

Table 1.--US-FCC personnel (World Weather Building operations)

1. Director: Thomas M. Kaneshige

2. Officer in Charge, Aircraft Specialists: Onial A. Thomas

	SOP-1	SOP-2
3. Duty Scientists:		
Paul R. Julian (NCAR)	X	X
John Pavone, Major, USAF (AWS)	X	
James K. Sparkman (FPO)	X	
Wayne E. McGovern (FPO)	X	X
4. Aircraft Specialists:		
Donald A. Thompson (NOAA/OA3)	X	X
Roger Sorenson, Capt., USAF (MAC)	X	
Samuel Trunzo, Capt., USAF (AWS)	X	
David Gurkin, Col., USAF (AWS)	X	
Ronald Barrick, Capt., USAF (MAC)		X
Delbert Simmons, Maj., USAF (MAC)		X
Charles Steverson, Capt., USAF (MAC)		X
5. Duty Coordinators:		
Donald J. Florwick, CMDR, NC (FPO)	X	X
Karen L. Cox, LTJG, NC (FPO)	X	X
David K. Howard, LTJG, NC (FPO)	X	X
Michael J. Kretsch, LTJG, NC (FPO)	X	X
Earl Snipes, CAPT, USAF (AWS)	X	X

6. Other FPO Members Who Assisted:

Kenneth W. Foulke
Warren H. Keenan

mainly to a diminishing number of available personnel, were necessary during the remainder of SOP-1. Work schedules for SOP-2 were quite stable, and the three categories of personnel (duty scientist, aircraft specialist, duty coordinator) were scheduled so as to provide for maximum work accomplishment by a minimum number of personnel. During the nonintensive periods of the SOPs, the center was manned during most of the daylight hours by duty coordinators. Table 1 lists the personnel who participated in the work of the US-FCC in the World Weather Building.

4.2 Observing Systems Support

The results of the coordination and operational support of U.S. components of the FGGE composite observing system are summarized below. The effectiveness of communications support, which was arranged prior to the start of field operations, is also indicated.

4.2.1 Special land-based upper air stations

The coordination of the upper air observing programs on Enewetak and Canton Islands worked very smoothly. All scheduled messages and a few special operational problem reports were received in a timely manner at the US-FCC. The success of this coordinating effort was due in part to the excellent cooperation of the special U.S. Army mobile upper air teams and also to the excellent (existing) military telecommunications system.

The coordination of the programs on Kapingamarangi and Woleai did not fare as well because of severe telecommunications difficulties. The planned system for communicating status reports from the island sites to the US-FCC was to use an HF radio link from the island sites to an appropriate Trust Territory District Center, where a teletype message was expected to be prepared and disseminated via teletype to the US-FCC. A few status reports were received at the US-FCC during the beginning of SOP-1, but severe problems with maintaining working generators at the observing sites resulted in the loss of some of the status reports. Since the 6th Weather Squadron (6WS) headquarters at Tinker AFB, Oklahoma, was in frequent radio contact with its mobile upper air tems on Kapingamarangi and Woleai, the US-FCC decided to make an informal arrangement with the 6WS to obtain status information directly from the 6WS. This modified procedure provided most of the needed information.

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were unfavorable, a similar halt or slowing down of the platform launches took place. The military teletype system provided excellent telecommunications for the necessary coordination.

For the determination of balloon distribution and platform level circulation patterns, the US-FCC relied solely upon the teletype printouts of balloon reports (COLBA) received via the GTS and the NMC tropical 150-mb analysis displays with data plots. There were significant problems with the COLBA reports received during SOP-1, which made it difficult to assess the distribution of platforms. The probable reason for the problems was the limited amount of time France had to check out its real-time processing and dissemination programs before declaring them operational. (The overall delays in the TIROS-N launch reduced this checkout time.) The situation improved markedly toward the end of SOP-1, and few problems were experienced during the remainder of the SOPs. Arrangements for obtaining copies of the NMC 150-mb analyses worked very well.

4.2.5 Tropical wind observing ship program

The success of the coordination of U.S. participation in the international TWOS operations varied from ship to ship and from ocean to ocean. The planned coordination effort called for each U.S. ship to transmit to the US-FCC a daily status report in a prescribed format. Ships operating in the Pacific and Atlantic Oceans were expected to telecommunicate their reports via HF radio to the nearest U.S. Coast Guard radio station for relay to the US-FCC. Ships in the Indian Ocean were expected to telecommunicate their reports to one of the U.S. Navy communications stations in the area for relay to the US-FCC. For outgoing messages from the US-FCC to the ships, plans called for the dissemination of messages via the reverse of the arrangements specified above. In view of the lateness in finalizing the ship operations plans, it appears likely that the planning arrangements with some of the ships' operators were never fully coordinated.

Overall, the reception of status reports from the NOAA ships (RESEARCHER, DISCOVERER, OCEANOGRAPHER, TOWNSEND CROMWELL and DAVID STARR JORDAN) was excellent, regardless of the ocean in which the ships were operating. This could be attributed in part to the more complete coordination effort achieved by the US-FCC prior to the start of ship operations. Reception of status reports from the USNS WILKES was spotty. Additionally, the ship was diverted from FGGE work to higher priority Department of Defense missions during part of SOP-2. The university ships (KNORR, GYRE, COLUMBUS ISELIN) did not communicate their status reports according to plans. As a result, the US-FCC in telephone coordination with the research institutions responsible for the operations of the ships was able to make arrangements to have each institution obtain the needed status information. The US-FCC then obtained the information by telephone from the institutions. Unfortunately, no such arrangements could be made over the weekends and on holidays, so status reports for these were obtained on the first working day following the weekend or holiday.

US-FCC personnel encountered significant difficulties in the dissemination of messages to the ships. During SOP-1, it was not always clear which coastal radio station was monitoring the radio transmission of each

ship, so there was an element of guess-work involved in identifying the radio stations to which the message should be addressed for relay to the ship. On a few occasions, messages were returned "un-sent" to the US-FCC because the addressed radio station did not know the whereabouts of the ship. In some instances, it was not possible to get messages to a ship. Overall, there was some improvement during SOP-2.

The US-FCC agreed to send twice-weekly status reports about the operations of each U.S. ship to the FGGE Operations Center. However, because the US-FCC Operations Plan and the international TWOS Operations Plan were not finalized until quite late, there were some mix-ups in the coordination between the US-FCC and the FGGE Operations Center. The format for the status reports prepared by the US-FCC were not exactly in agreement with the format prescribed by the FGGE Operations Center. This problem was resolved during the period between the two SOPs. On a few occasions throughout the SOPs, status reports were not sent to the FGGE Operations Center. This was due to temporary breakdowns in the internal tracking system of scheduled incoming/outgoing messages.

4.2.6 Southern Hemisphere drifting buoy system

The deployment of U.S. drifting buoys for SOP-1 was planned in considerable detail and there was only a minimum amount of involvement of the US-FCC in this activity. During the deployment phase, each of the deployment ships regularly transmitted buoy checkout and deployment reports to the US-FCC. The US-FCC in turn summarized the information and transmitted weekly status reports of U.S. buoy deployments to the FGGE Buoy Logistics and Deployment Center in Vancouver, Canada.

The United States also participated in the international re-seeding effort for SOP-2 by air-deploying 18 buoys from two USAF C-141 aircraft operating out of Argentina and Australia/New Zealand. Some of the expected buoy deployment reports from the aircraft staging locations were not received at the US-FCC until after the aircraft and personnel returned to the United States. However, since there was no great urgency for the deployment information, the "apparent" loss of the near-real-time information did not have any impact on operations.

4.2.7 Automated AIREPS

US-FCC involvement in monitoring the status of operations of wide-bodied jet aircraft participating in the Aircraft to Satellite Data Relay (ASDAR) program was very limited, since personnel responsible for the ASDAR program were maintaining a close watch over the program. The US-FCC did monitor the receipt of ASDAR reports via the GTS by collecting all available ASDAR bulletins and delivering them to ASDAR program personnel.

4.3 Data Management Support

The US-FCC began monitoring the activities of U.S. FGGE data management centers in July 1978. From monthly information received by mail, the US-FCC summarized the activities at each center and prepared monthly status

reports of U.S. FGGE Data Management Activities. These reports were mailed to the international FGGE Operations Center from July 1978 through December 1979, when the US-FCC terminated operations. (Data management status reports will continue to be prepared through June 1980 by the U.S. GARP Office.) This activity was very successful.

5. DIFFICULTIES ENCOUNTERED AND ACTIONS TAKEN

As with most field experiments, no amount of planning can take into account all that eventually occurs and the success or failure of the operations is somewhat dependent on the creativity and flexibility of the individuals participating in the experiment. The success of the US-FCC operations is due in part to the planning effort, but also to the inventiveness, adaptability, and hard work of the individuals who participated in the work of the center.

There were some difficulties encountered in conducting the operations of the US-FCC in the World Weather Building. Some of the operational difficulties have already been discussed in section 4 and need not be repeated here. The following are difficulties associated with personnel and physical arrangements.

5.1 Adverse weather conditions. The Washington, D. C. area was hit by a record 24-inch snowfall on 18-19 February 1979, which completely paralyzed the city and its surrounding areas. The unfortunate aspect of this storm was that the heaviest snowfall occurred during the 4-hour period when the US-FCC was not manned on the evening of 18 February and the individual going off duty was able to leave the US-FCC, but the individual who was supposed to report for duty early on the 19th was completely snowbound. As a result, it was not until 1100 EST on 20 February 1979 that the first US-FCC individual was able to make his way into the US-FCC. This meant that the US-FCC was not manned for nearly 40 consecutive hours during the last days of the extended SOP-1 operations.

5.2 Building entry difficulties. Entry into the World Weather Building, where US-FCC operations were conducted during the SOPs, was limited to individuals with building passes. The US-FCC made special arrangements with the Building Services Officer to ensure that US-FCC duty personnel would be able to gain access to the building during all hours of the day. On a few occasions, the building guards made it difficult for duty personnel to gain entrance, but in every case, the affected individual was able to gain entry. (All incidents were subsequently reported to the Building Services Officer.)

5.3 GTS teletype printer. The US-FCC was unable to obtain a GTS teletype printer on its premises during SOP-1. The printer was needed to monitor the receipt of near-real-time aircraft dropwindsonde, constant level balloon, drifting buoy, and conventional upper air reports. As a result, US-FCC duty personnel had to pick up the information at the Federal Office Building No. 4 in Suitland, Maryland. This made it difficult to monitor

the operations of these programs. The situation was resolved with the installation of a printer prior to the start of SOP-2.

5.4 Tracking of incoming/outgoing messages, charts, satellite photos, etc. There was a considerable amount of information flowing in and out of the US-FCC, and some information was lost or misplaced. Also, some of the outgoing messages were mistyped by the communications center or, worse yet, not drafted for delivery to the communications center. Where necessary, a check was made with the communications center to locate missing (scheduled) incoming reports and copies of the reports were usually accounted for. In the case of erroneous or missing outgoing messages, US-FCC usually followed up with corrected messages.

6. CONCLUSIONS AND RECOMMENDATIONS

Overall, US-FCC operations were very successful. The individuals who participated in the work of the center did an excellent job in resolving the numerous difficulties which arose and in maintaining the schedule of planned operations. The support from the NWS Communications Operating Branch in handling all incoming and outgoing teletype traffic was outstanding, as was the support from the NESS Satellite Analysis Branch in providing satellite weather support for FGGE aircraft dropwindsonde missions. The NMC made all the necessary arrangements for the physical location and furniture for the center, and provided several types of guidance products used in conducting the day-to-day operations.

Regarding recommendations for coordinating future experiments, two important ones come to mind. These are:

6.1 Operations plans for the Operations Center or Coordinating Center should be developed, coordinated, and finalized in detail well enough in advance of the start of operations, so that a thorough checkout can be conducted before the start of actual operations. In the case of international experiments, and to a certain extent national experiments, this is always a problem. Final systems checkouts always seem to occur during the early phases of the actual operation. Nevertheless, this should be a goal for any future experiment.

6.2 Procedures for tracking the flow of incoming and outgoing information should be developed in detail prior to the start of operations and adhered to during the operations. This was a problem during FGGE, because the procedures were not developed in as much detail as was needed. This resulted in an occasional loss or misplacement of incoming information and an occasional failure to disseminate scheduled messages. A good followup system is also needed to ensure that errors introduced in the preparation of messages are corrected before the messages are disseminated. A system for numbering all outgoing messages should be used to provide for better control over outgoing information.

CHAPTER 2

OPERATIONAL U.S. SATELLITES
NESS

By
Robert N. Green (NESS)

1. INTRODUCTION

The National Environmental Satellite Service (NESS) has played a major role in the First GARP Global Experiment (FGGE) - the Global Weather Experiment. Sea surface temperature values, cloud motion vectors, and vertical temperature soundings were derived for the FGGE Level II-b Research Data Set from data obtained from the NESS fleet of polar-orbiting and geostationary operational environmental satellites. In addition, the operational satellites provided image products for the archive at the National Climatic Center and served as a host to a Data Collection and Platform Location System for terrestrial and atmospheric instrumented platforms. Through the use of the operational satellites, thousands of meteorological measurements have been added daily to the total number of observations obtained through more conventional methods (e.g., surface and upper air observations).

2. U.S. OPERATIONAL SATELLITE SYSTEM

NESS operated two environmental satellite systems during the Global Weather Experiment. These were the polar-orbiting, sun-synchronous satellites (NOAA-5, TIROS-N, and NOAA-6), which provided daily global coverage and the Geostationary Operational Environmental Satellites (GOES). The polar-orbiting data provided mainly global quantitative products such as vertical temperature soundings of the atmosphere and sea surface temperatures. The GOES satellites provided environmental data for the Earth's disk facing each satellite at periodic intervals, usually every 30 minutes. The data from both satellite systems were routinely processed by NESS into a variety of quantitative and image products, which were then distributed to users. A system of five geostationary satellites operated during the operational year of the Global Weather Experiment (see Figure 1). The satellite over the Indian Ocean was also a U.S. satellite and its operation is discussed later in this report by Kahwajy (see Chapter 3).

The GOES system consisted of operating satellites at 75°W and 135°W, the ground command and data acquisition station at Wallops Island, Virginia, the ground data acquisition station in Washington, D. C., and a central data distribution system. A total of five different satellites were called upon to participate in the operational U.S. satellite system during the FGGE Build-up and Operational Years from December 1, 1977 - November 30, 1979. These were the Synchronous Meteorological Satellite (SMS-1), a NASA prototype for the GOES, launched in May 1974; SMS-2, launched in February 1975; GOES-1, launched in October 1975; GOES-2, launched in June 1977; and GOES-3, launched in June 1978.

At the start of the FGGE Build-up Year, the operational configuration of satellites had GOES-2 at 75°W (GOES-EAST) and SMS-2 at 135°W (GOES-WEST), fixed over the Equator at an altitude of about 36,000 km. The two satellites were positioned to provide overlapping and continuous coverage of the Western Hemisphere. On April 4, 1978, GOES-1 replaced SMS-2 at 135°W; GOES-1 was replaced on July 13, 1978, by the newly-launched GOES-3 which remained at the GOES-WEST station through the end of the Operational Year. At the GOES-EAST

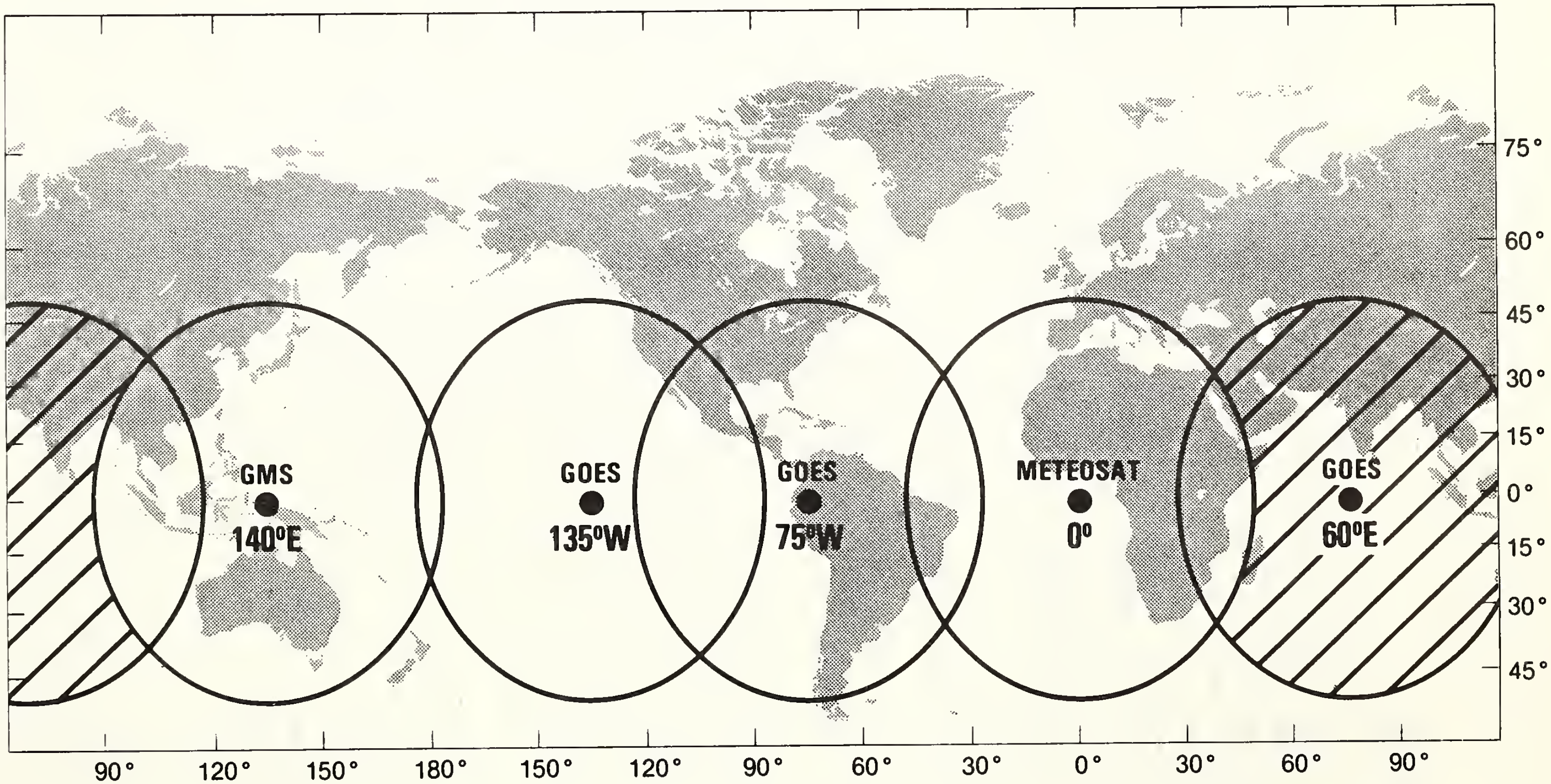


Figure 1.--Coverage for quantitative use of imagery from the five geostationary satellite systems (50° from sub-point).

position, SMS-1 replaced GOES-2 on January 26, 1979, and a switch to SMS-2, which held for the duration of the experiment, was completed on April 19, 1979.

The primary instrument of the SMS and GOES was the Visible and Infrared Spin-Scan Radiometer (VISSR). The VISSR provided concurrent observations in the infrared (IR) (10.5 to 12.5 μm) and in the visible (VIS) (0.55 to 0.75 μm) regions of the spectrum. The VISSR provided a full-disk view every 30 minutes. (More frequent scanning could be obtained at the expense of spatial coverage.) The VIS channel provided 1-km daytime coverage whereas the IR channel provided 8-km daytime and nighttime coverage.

During the 2-year period of the FGGE observational phase, two different polar-orbiting satellite systems were used. At the start of the Build-up Year, the NOAA-5 satellite was operational. The primary instruments carried were the Vertical Temperature Profile Radiometer (VTPR) with eight channels varying in central wavenumber from 668 cm^{-1} to 833 cm^{-1} and the Scanning Radiometer (SR), a 2-channel instrument sensitive to radiation in the 0.5-0.7 μm visible region and in the 10.5 to 12.5 μm infrared (IR) "atmospheric window" region. NOAA-5 had a nominal orbital altitude of 1,464 km, crossing the Equator southbound at 9 a.m. local mean time with a nodal period of 115 minutes.

In October 1978, the next generation of polar-orbiting satellites was introduced: the TIROS-N series (see Schwalb, 1978, for a detailed review of the TIROS-N series). During that month, TIROS-N was launched, followed in June 1979 by the launch of NOAA-6. These satellites had nominal altitudes of 866 km and 830 km with a southbound Equator crossing time of 3:14 a.m. and 7:32 a.m. local mean time, respectively. The nodal period was 101 minutes.

2.1 Primary FGGE environmental satellite sensors

The TIROS Operational Vertical Sounder (TOVS) was a 3-instrument system consisting of:

o The High Resolution Infrared Radiation Sounder (HIRS/2)--a 20-channel instrument, which makes measurements primarily in the infrared portion of the spectrum (see Table 1). The instrument was designed to provide data that will permit calculation of (1) a temperature profile from the surface to 10 mb; (2) water vapor content in three layers in the atmosphere; and (3) total ozone content.

o The Stratospheric Sounding Unit (SSU)--employing a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel were determined by the pressure in a carbon dioxide gas cell in the optical path. The amount of dioxide in the cells determined the height of the weighting function peaks in the atmosphere.

o The Microwave Sounding Unit (MSU)--a 4-channel Dicke radiometer, which makes passive measurements in the 5.5-mm oxygen band. This instrument, unlike those making measurements in the infrared region, is little affected by clouds.

Table 1.--HIRS-2 channels

TIROS-N/NOAA-A HIRS-2 Channel 1 Nominal Wavenumber (cm^{-1})	669
TIROS-N/NOAA-A HIRS-2 Channel 2 Nominal Wavenumber (cm^{-1})	679
TIROS-N/NOAA-A HIRS-2 Channel 3 Nominal Wavenumber (cm^{-1})	690
TIROS-N/NOAA-A HIRS-2 Channel 4 Nominal Wavenumber (cm^{-1})	702
TIROS-N/NOAA-A HIRS-2 Channel 5 Nominal Wavenumber (cm^{-1})	716
TIROS-N/NOAA-A HIRS-2 Channel 6 Nominal Wavenumber (cm^{-1})	732
TIROS-N/NOAA-A HIRS-2 Channel 7 Nominal Wavenumber (cm^{-1})	749
TIROS-N/NOAA-A HIRS-2 Channel 8 Nominal Wavenumber (cm^{-1})	900
TIROS-N/NOAA-A HIRS-2 Channel 9 Nominal Wavenumber (cm^{-1})	1030
TIROS-N/NOAA-A HIRS-2 Channel 10 Nominal Wavenumber (cm^{-1})	1229
TIROS-N/NOAA-A HIRS-2 Channel 11 Nominal Wavenumber (cm^{-1})	1345
TIROS-N/NOAA-A HIRS-2 Channel 12 Nominal Wavenumber (cm^{-1})	1490
TIROS-N/NOAA-A HIRS-2 Channel 13 Nominal Wavenumber (cm^{-1})	2190
TIROS-N/NOAA-A HIRS-2 Channel 14 Nominal Wavenumber (cm^{-1})	2210
TIROS-N/NOAA-A HIRS-2 Channel 15 Nominal Wavenumber (cm^{-1})	2250
TIROS-N/NOAA-A HIRS-2 Channel 16 Nominal Wavenumber (cm^{-1})	2275
TIROS-N/NOAA-A HIRS-2 Channel 17 Nominal Wavenumber (cm^{-1})	2360
TIROS-N/NOAA-A HIRS-2 Channel 18 Nominal Wavenumber (cm^{-1})	2514
TIROS-N/NOAA-A HIRS-2 Channel 19 Nominal Wavenumber (cm^{-1})	2680
TIROS-N/NOAA-A HIRS-2 Channel 20 Nominal Wavenumber (cm^{-1})	14440 (Vis Channel)

The Advanced Very High Resolution Radiometer (AVHRR) was a 4-channel scanning radiometer sensitive in the visible, near-infrared and infrared window regions. This instrument provided data for central processing at full resolution (1.1 km).

Also onboard the TIROS-N series was the ARGOS Data Collection and Platform Location System which was provided by the Centre National d'Etudes Spatiales (CNES) of France. This was a random-access system to acquire data from fixed and free-floating terrestrial and atmospheric platforms. Platform location was made possible by ground processing of the Doppler measurements of carrier frequencies. Data collected from each platform included identification as well as environmental measurements. The primary uses of the ARGOS system during FGGE were the location determination and interrogation of the drifting buoy and constant level balloon systems.

The ARGOS system worked very well since the operational start of TIROS-N on December 15, 1978. The data were moved from the satellite data stream and stored in computer disk storage until the data were sent via land line to New York City, NY, for transmission to Paris, France, through a communications satellite and, again, by land line to Toulouse, France, for final processing by CNES. The remotely accessed data were planned to be delivered to CNES within three hours, and this requirement was met in most cases throughout the Operational Year.

3. U.S. OPERATIONAL SATELLITE PRODUCTS FOR FGGE RESEARCH

Three major NESS products were incorporated into the FGGE research data set: Satellite cloud motion vectors, sea surface temperatures, and vertical temperature sounding data. These products were operationally produced as part of the NESS commitment to various national and international programs. A decision was made in NESS to keep FGGE support operations separate from normal operations, since FGGE required the products in a delayed delivery mode; thus, there was no operational impact on the NESS data processing facility. The U.S. national archive of magnetic tapes of all operational satellite products was used as input data to produce FGGE tapes according to the Formats for International Exchange of Level II Data Sets. These tapes were prepared and delivered on a regular schedule to the FGGE Level II-b Space-Based and Special Observing Systems Data Center in Norrkoping, Sweden. Each product line has had a unique history during the FGGE period and will be discussed individually.

3.1 Cloud Motion Vectors

NESS produced these vectors from GOES images three times each day, at 0000Z, 1200Z, and 1800Z, using computer automated techniques for most low-level (900-mb) vectors and manual film loop methods for middle- and upper-level vectors.

A cross-correlation, computer model provided the automated detection and displacement measurements of selected digital GOES imagery to determine low-level wind vector estimates. Infrared data were aligned and displacement measurements were computed from two images that are 30 or 60 minutes apart.

Approximately 150 low-level vectors were produced from each satellite for each production time.

Middle- and upper-level vectors were produced by meteorologists viewing a time-lapse movie loop of six GOES images with a movie projector which displayed the movie on a digitized plotting board. The resulting cloud displacements were translated into cloud motion vectors by a computer program. The meteorologists also appended cloud height estimates to these vectors and made a final assessment of both manual and automated vectors before finalizing the operational wind vector data set (Bristor, 1975). Approximately 1,400 satellite cloud motion vectors were produced each day from both techniques.

Very few problems occurred during the FGGE period with cloud motion vectors. A few minor changes were made to the International Level II Data Exchange formats effective October 1978, but this did not cause any delays in NESS processing.

Table 2 summarizes the NESS production of cloud motion vectors for the FGGE research data set.

3.2 Sea Surface Temperatures

Sea surface temperature (SST) observations produced by NESS during the two years of FGGE had a varied history of three different computational methods and two different satellites. The initial method was a statistical histogram analysis of data from the NOAA-5 SR sensor's infrared spectral window with atmospheric attenuation corrections derived from the VTPR sensor data (see Brower et al for a detailed discussion). This resulted in nearly 10,000 (4,000 of highest quality) observations daily with a horizontal resolution of about 100 km. On March 16, 1978, an equipment malfunction on NOAA-5 stopped the flow of SR data.

A backup technique was quickly placed into the SST operation which used only VTPR data. The SST observation used a single spot value from the VTPR thermal window band which was moisture-corrected and determined cloud free by using various combinations of VTPR channels. Because this method worked only in cloud-free areas, the quantity of SST's dropped to 4,000-5,000 observations per day, but the accuracy remained comparable to the SR method.

The TIROS-N SST processing system was declared operational on March 1, 1979, with an overlap operation with the NOAA-5 SST system beginning January 1, 1979, and provided for a series of changes to the SST products. Some of the more significant changes were:

o The horizontal resolution of a nominal SST observation was increased to about 50 km.

o The number of highest quality observations was increased to approximately 30,000-40,000 per day or nearly one million per month.

o Cloud detection and atmospheric attenuation correction was improved through the use of TOVS data.

The retrieval method used was a maximum likelihood technique (a standard statistical procedure) which was designed to estimate the mean clear radiance by checking only the warmest observations from a target of AVHRR infrared data. This method was simple and computationally fast and had been thoroughly tested on NOAA-5 SR data. The mean clear radiance was moisture-corrected using a combination of the various TOVS channels.

Evaluation of the early operational observations showed systematically colder satellite measurements as compared to ship observations in the tropics. Stricter cloud tests in the tropics eliminated much of this cold bias after February 1, 1979. Satellite SST observations in the middle-and high-latitude regions tended to have a slight warm bias during the summer.

Table 2 summarizes the NESS production of sea surface temperatures for the FGGE research data set.

3.3 Vertical Temperature Profiles and Clear Radiances

One of the more important types of data included in the Level II-b data set is also one of the most complex operational satellite products: Vertical temperature profiles. This product is of great interest to the global atmospheric modeller, because it fills the void of information about the vertical temperature structure over the oceans. Two different satellite and production systems were used during FGGE: The VTPR instrument on NOAA-5 and the TOVS instrument on TIROS-N and NOAA-6.

In the NOAA-5 data flow, radiance values derived from calibrated and earth-located VTPR channel data were passed to a clear radiance program, which operated to eliminate the effects of clouds through comparisons of adjacent VTPR data, sea surface temperature, and approximate first guess vertical temperature structure. The temperature profiles were obtained through a modified, minimum-root-mean-square solution of the radiative transfer equation (see McMillin et al, 1973, for further details). The average daily number of clear radiance retrievals was 1300-1400, and approximately 900-1000 temperature profiles were processed from the clear radiance retrievals.

On March 1, 1979, the sounding processing system using TOVS data from TIROS-N was declared operational after about three months of test and evaluation following the turnover of the spacecraft to NESS. The operational system was comprised of the following components: Preprocessor, TOVS atmospheric radiance module, TOVS mapper, TOVS retrieval module, and output products module. The preprocessor reformatted the raw data from HIRS/2, MSU, and SSU into a form convenient for other modules, and made limb corrections and water vapor attenuation corrections. The atmospheric radiance module computed clear-column radiance measurements by statistical regression techniques of various instrument channel combinations based upon the determination of a clear, partly cloudy, or cloudy target (see Smith and Woolf, 1976; and Smith et al., 1979; for a detailed discussion of the science of retrieval methods). After all the needed data were mapped and analyzed, the retrieval module accessed the clear radiances and produced the retrievals of atmospheric temperatures, water vapor profiles, geopotential height, total ozone, average cloud amount, and albedos. The parameters were quality controlled and processed into numerous products for the user. Some of these parameters have not met operational standards and, thus, have limited

Table 2.--Summary of monthly totals for satellite-derived observations archived by NESS for FGGE.

Date	Sea Surface Temperature	Cloud Motion Vectors	Atmospheric Soundings	Clear Radiances
Jan 1978	373648*	48488	22875*	38125*
Feb 1978	337489*	43395	22192*	34142*
Mar 1978	265169*	45590	22972*	37660*
Apr 1978	163718*	46069	21329*	34966*
May 1978	169176*	46507	22347*	35472*
Jun 1978	173079	49736	28192	46851
Jul 1978	162474	52427	27841	46635
Aug 1978	125024	53811	23492	39756
Sep 1978	138764	47109	24056	37529
Oct 1978	135540	46577	24830	38174
Nov 1978	125504	50147	27189	41565
Buildup Year Total	2,169,585	529,856	267,315	430,875
Dec 1978	144488	45008	29620	42828
Jan 1979**	1123900	41285	217693	218155
Feb 1979	657330	41483	191192	191195
Mar 1979	933952	45076	235237	238840
Apr 1979	813396	39443	228410	230524
May 1979	984650	44431	230412	230420
Jun 1979	961848	44491	247558	247836
Jul 1979	904778	44305	241765	244493
Aug 1979	1046012	49566	240030	245320
Sep 1979	1033572	48058	239023	244094
Oct 1979***	963998	50323	324730	325086
Nov 1979	708996	52518	390349	390349
Operational Year Total	10,276,920	545,987	2,816,019	2,849,140
Grand Total	12,446,505	1,075,843	3,083,334	3,280,015

* Estimated

** TIROS-N Data Operational January 1, 1979

*** NOAA-6 Data Operational October 16, 1979

distribution (e.g., tropopause pressure and temperature). The number of clear radiance and atmospheric profile observations derived has averaged about 7,500 per day with a horizontal spacing of 250 km. With the operational use of NOAA-6 TOVS data on October 16, 1979, the daily total doubled to 15,000. However, by early November a hardware problem in the ground data handling system restricted the amount of TOVS data that could be processed. An effort was made to process as many orbits of TIROS-N data as possible to provide a nearly complete, 1-satellite, global coverage at the expense of losing many NOAA-6 orbits. The period November 23-28 was hit hardest with a total of 50 hours of missing TIROS-N data.

Table 2 summarizes the NESS production of vertical temperature profiles and clear radiances for the FGGE research data set.

In order to provide FGGE with operational TOVS soundings for as much of the Operational Year as possible, a special effort was instituted to process TOVS data from January 1 through February 28, 1979, in a delayed "catch-up" mode. Raw TOVS data which had been archived during this period were processed through a parallel operation from March 16 to May 4, 1979, which provided operational sounding data for FGGE as though it had been acquired in real-time processing. This special effort also allowed NESS to test its data handling and computer facility for the dual TIROS-N/NOAA-6 satellite operation.

During the start-up of any new complex system of satellite instruments and ground data handling hardware and software, various problems and errors will arise which will affect the final output products; such was the case with TIROS-N. The scheduled launch of TIROS-N was delayed several months; however, the FGGE time schedule did not slip. NESS scientists had to compromise with a sounding system placed into an operational state without benefit of several months of problem-solving time, in order to meet the Level II-b data delivery schedule. Two proposed operational sounding parameters (tropopause and ozone parameters) were deleted from the FGGE data set for the duration of the Operational Year because of the lack of time for complete test and evaluation. Other data and systems problems resulted in the production at specific times of unusable or unreliable products which were also deleted from the final data set. These items are listed in Table 3.

4. DATA MANAGEMENT OF U.S. OPERATIONAL SATELLITE PRODUCTS FOR FGGE RESEARCH

All U.S. operational satellite products to be archived for FGGE research were to be delivered to the FGGE Level II-b Space-Based and Special Observing Systems Data Center in Norrkoping, Sweden. The medium of exchange was standard computer-compatible magnetic tapes structured according to the formats for the International Exchange of Level II Data Sets as established by the WMO (see Volume 3, FGGE Implementation/Operations Plan - FGGE Data Management Plan; Appendix 10). The original, agreed-upon shipment schedule to the Swedish Data Center was to have in the mail by the fifteenth of a month all data for the previous month (example: by May 15, 1978, ship all data for April 1-30, 1978). In most cases, this schedule was met during the Build-up Year with GOES and NOAA-5 data. By end of the Build-up Year, NESS computer resources

Table 3.--Deleted data and precautionary notes for TIROS-N and NOAA-6 sounding data in the level II-b data set.

Items	Time period of FGGE Level II-b archive tapes from NESS for 1979 (Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.)
1. Deleted all tropopause parameters	*1 Jan.-end of FGGE*
2. Deleted all ozone parameters	*1 Jan.-end of FGGE*
3. Deleted all layer mean temperatures above 100 mb, if the observation is poleward of 74°N and 74°S	*1 Jan.-11 Feb.*; *1 Mar.-21 Apr.*
4. Deleted 11 precipitable water parameters	*1-21 Jan.*; *1 Mar.-14 Apr.*
5. Deleted complete observation if between 60°S-75°S latitude and MSU channel 4 temperature is less than 219 K	*15 Apr.- 5 May*
6. Deleted complete observation if between 55°S-60°S latitude and MSU channel 4 temperature is less than 215 K	*29 Apr.-26 May*
7. Precautionary note: Possible low temperature bias near surface and in regions of persistent low-level cloudiness	*1 Jan.-15 Jul.*
8. Deleted complete observations because of bad data between these times:	
18 July 1500 GMT-1700 GMT	Δ
24 July 1400 GMT-1600 GMT	Δ
29 July 1300 GMT-1500 GMT	Δ
1 August 0900 GMT-1130 GMT	Δ
9. Precautionary note: A few bad retrievals may be present due to an ingest problem	*1 Jul.-3 Aug.*
10. Precautionary note: Some observations may be mislocated up to 70 km due to TIROS-N spacecraft attitude problem, 4 Nov. 0930 GMT-8 Nov. 1523 GMT	*4-8 Nov.*
11. Deleted all NOAA-6 temperature data above 3 mb level	*16 Oct.-30 Nov.*
12. Precautionary note: Numerous data coverage gaps occur due to ground system hardware problem 23-28 Nov.	*23-28 Nov.*
13. Precautionary note: Possible low temperature bias in soundings derived from cloudy microwave retrievals made in precipitation	*1 Jan.-end of FGGE*

were more difficult to obtain because of check-out of the TIROS-N operating system. The shipment schedule was modified so that the shipment of data tapes would be made by the end of the month instead of the fifteenth. This modification allowed greater flexibility within NESS for tape production but still was well within the Swedish Data Center processing schedule. The new schedule was met throughout the Operational Year for the GOES cloud motion vector and TIROS-N sea surface temperature products. The TIROS-N clear radiance and sounding products encountered the following numerous problems which caused extended delays in the scheduled shipments: The delayed start of the TOVS operational system, the catch-up processing, NESS archiving software problems, a tape format change requested by the Swedish Data Center which was not fully resolved until early June, and the need to reprocess all TOVS data from January 1, 1979. The processing and shipping of TOVS data tapes gradually got back on schedule by the end of the Operational Year.

A normal, monthly shipment of tapes during the Build-up Year consisted of six tapes: One tape each of cloud motion vectors and sea surface temperatures and two tapes each of clear radiances and soundings. With the start of TIROS-N operational data, one tape was produced weekly for each of sea surface temperatures, clear radiances, and soundings; the dual TIROS-N/NOAA-6 operation raised the total to two tapes per week for both clear radiances and soundings.

A number of tapes had to be re-sent during the Build-up and Operational Years for a variety of reasons: Parity errors, unreadable tapes, format overflows (asterisk-filled fields), and undelivered tapes. In many cases, the only action that had to be taken by NESS was to make a copy of the back-up tape in question and reship. Other problems usually involved minor computer processing and reshipping. One deviation from the FGGE Data Management Plan should be noted: The first test tapes sent to the Swedish Data Center were produced at 1600 bits per inch (bpi) instead of the required 800 bpi. The Swedish Data Center had no problem reading the tapes, so a bilateral agreement between NESS and the Swedish Data Center was reached that all U.S. operational satellite tapes would have a density of 1600 bpi for the duration of FGGE. This reduced substantially the total number of tapes which had to be shipped, especially of TIROS-N products.

In addition to the regular shipment schedule, NESS also participated in the End-to-End Test for the first Special Observing Period. A NESS scientist hand-carried to the Swedish Data Center magnetic tapes of all NESS operational products, including the first available TIROS-N products, for the period January 15-19, 1979. A few minor problems occurred in processing the data tapes at the Swedish Data Center; however, all of these were solved with minimal delay. The consensus of the participants in the data-gathering and merging phase of the End-to-End Test was that the FGGE Level II-b data producers had reliable data processing operations, which would enhance the chances for success of the Global Weather Experiment.

5. CONCLUSIONS AND RECOMMENDATIONS

The NESS participation in the Global Weather Experiment as the U.S. Operational Satellite Data Producer progressed quite smoothly through the Build-up and Operational Years despite the quantity of data that had to be

exchanged and the mid-stream switch-over to an entirely new polar-orbiting satellite system. Several items should be mentioned in retrospect, which may help in the planning of future experiments.

5.1 Level II data exchange formats

It is highly desirable that the final data tape formats for an international experiment be compatible for use on as many computer systems as possible. However, when only two data centers are involved in the exchange of data, especially in quantities associated with satellite data products, the Level II data formats used for the FGGE are rather inefficient from a computer system processing and a tape logistics point of view. If the two centers can agree on a higher density recording level and the use of binary recording code instead of EBCDIC code, fewer tapes would have to be produced, shipped, and stored, and less computer time would be required. Data producers may have a workable data format already in use which would be compatible with the receiving data center, thus saving time and money for both centers.

5.2 Acceptable error rate for exchanged tapes

The data management plan for an experiment of the scope of FGGE should list the acceptable error rates for any given tape that will be tolerated at each data center before that tape is rejected and the data producer is asked to reprocess the data. The goal of each data producer should be 100% correctness; however, in processing millions of data parameters, a few inadvertent errors are bound to occur. The error rate could be as small as 0.01% of all observations on a tape before reprocessing is requested. During FGGE, several tapes were reprocessed by NESS in which only one or two parameters in one observation were incorrect out of a total of 100,000 observations.

5.3 The use of TELEX messages for tracking

In a large international experiment such as FGGE, communication among participants is always a problem. The use of TELEX messages for the expedient flow of vital information between NESS and the Swedish Data Center was greatly appreciated despite the high cost of the service.

5.4 Tapes lost in shipment

It had been expected that some problems would exist in shipping magnetic tapes via international air mail, but this did not materialize. The few tapes that had parity errors or were unreadable may have been due to the passing of the tapes near magnetic fields of motors, but this would be very difficult to prove. Only two shipments of ten tapes each appeared to have been lost in the mail, but they eventually arrived after replacement tapes had already been shipped. These shipments had been delayed by Swedish Customs despite the regular customs form that had been attached to the box. Experiment planners should check early with all Customs Offices for proper clearance procedures.

CHAPTER 3

GOES, INDIAN OCEAN

By
F. Kahwajy (NESS)
F. Mosher (U. Wisconsin)

1. INTRODUCTION

Five geostationary satellites were planned for the FGGE operations, originally including a Soviet satellite at 60°E. The Soviets, however, informed the World Meteorological Organization (WMO) that their geostationary satellite would not be available in time to support FGGE. Contingency plans were then implemented to minimize the impact of the absence of the USSR satellite. This action resulted in a decision whereby the United States provided a replacement satellite which was then operated by the European Space Agency (ESA) for the operational year of FGGE.

In implementing this back-up plan, the United States moved the GOES-1 satellite to a position over the Indian Ocean and provided an antenna system and electronic equipment for satellite acquisition and control. This equipment was installed at Villafranca, Spain, for ESA operation. The satellite data were recorded on digital video cassettes and computer-compatible tapes and shipped to the University of Wisconsin. The Space Science and Engineering Center (SSEC) at Wisconsin processed the tapes and measured cloud drift winds which were sent to Sweden as part of the FGGE Level II-b data base. The full resolution digital archive of the GOES-Indian Ocean images is stored at SSEC and is available to scientific investigators. The GOES-Indian Ocean performed well except for the problem of the infrared sensor having sporadic outages after March 1979.

2. GROUND STATION AND SATELLITE OPERATIONS

The GOES ground station at the ESA Villafranca site consisted of a 13-meter S-band antenna system and two vans which contained the satellite control, data conditioning equipment, and the recording equipment. An antenna under construction to support another experiment was diverted to Villafranca. Much of the command and control system was borrowed from NASA and NOAA stations. Existing contracts were modified to include new equipment. Thus, a complete ground station including command and control telemetry receive and transmit, antenna receive and control, synchronizer data buffer, and recording equipment was assembled in less than six months.

At Darmstadt, Germany, ESA made changes in their control center to accommodate the GOES satellite. New software was written using NOAA-supplied specifications to handle GOES telemetry and to provide a GOES orbital tracking system.

NOAA provided the U.S. management of this crash effort, while funding was shared by the National Science Foundation, NASA, and NOAA. RF Systems Inc., installed the antenna system at Villafranca, while Westinghouse Electronic Corporation provided the system engineering, integration, and testing. SSEC provided the data recording equipment. The Air Force airlifted the equipment to Spain. ESA prepared the site at Villafranca, including the provision of concrete pads for antenna and equipment vans, the provision of electrical power, and the provision of communication links between Villafranca and the control center located at Darmstadt, Germany. A logistic system was established to provide spare parts from the United States, while other consumables such as magnetic tapes and archive cassettes were furnished by ESA. Manpower to operate and maintain the station was provided by ESA.

NOAA trained the station operational and maintenance personnel and helped ESA develop detailed procedures for the operation of the satellite and ground station equipment. The operational procedures were essentially the same as those for the U.S. operated GOES as described by Herkert, et al. (1975) and Jessie, et al. (1975).

The GOES-1 was initially moved from its position at 135°W to about 10°W where both NOAA and ESA could operate the satellite. After ESA was fully trained in the satellite operations, the satellite was moved to 58°E over the Indian Ocean. It arrived in November 1978 and was fully operational in time for the start of FGGE.

The normal operation schedule of the satellite had scans every half hour. Table 1 has the normal operations schedule, and Table 2 has the operations schedule for June, July, and August 1979. In addition to the half-hour scans, there were periods of 15-minute rapid scans from 8:00 to 9:15 GMT and 20:30 to 21:15 GMT each day. These 15-minute scans went from scan count 300 to scan 1500 (approximately 43°N to 43°S) and were used for making mesoscale wind sets in the tropical regions. During the months of June, July, and August, rapid scans of 10 minutes between images were made from 6:00 to 9:20 GMT between scans 450 and 1250 (approximately 31°N to 22°S). These rapid scans were used for mesoscale wind sets in the tropical MONEX region and to measure sea surface stress using sun glint in the Arabian Sea region.

The infrared sensors on the GOES-1 were calibrated weekly and encoded using the NOAA standard table. Since the GOES-1 had been used for several years previously as an operational satellite, its infrared calibration characteristics were reasonably well known. Prior to FGGE, a number of calibration encoding tapes were prepared. On a weekly basis, a computer tape which contained the calibration shutter information was shipped from Spain to NESS at Suitland, Maryland. The same calibration procedure as described by Bauer and Lienesch (1975) was used for GOES-1. The infrared calibration information was telexed to Spain where the correct calibration tape was loaded. Hence, the quality of the infrared sensor calibration was maintained throughout FGGE to the same degree as the other U.S. geostationary satellites.

The image data from GOES-1 were recorded on digital cassettes and computer tapes. The digital cassettes contained the full resolution output of the satellite. This prototype recorder was designed and built at SSEC by E. Suomi. It uses a modified Sony video recorder which can store 21 gigabits on a single cassette. Five cassettes per day were used. In addition to the cassettes, computer-compatible tapes were made of reduced resolution image data using the Offline Data Ingest System (ODIS) supplied by SSEC. The ODIS had a TV monitor in addition to the tape capability so one could see what data were being recorded, played back, or just being sent from the satellite. The archives were quality controlled by playing them back into the ODIS and checking the image quality. The ODIS was also used to record reduced resolution data for use by cloud tracking groups at SSEC in the U.S., Deutsche Forschungs- und Versuchsanstalt fur Luft- und Raumfahrt in Germany,

Table 1.--Normal GOES-1 FGGE VISSR operation schedule (Note: See Table 2, this chapter, for June, July, and August 1979 schedule.)

TIME GMT	VISSR action	TIME GMT	VISSR action
0000	Full scan	1200	Full scan
0030	Full scan	1230	Full scan
0100	Full scan	1300	Full scan
0130	Full scan	1330	Full scan
0200	Full scan	1400	Full scan
0230	Full scan	1430	Full scan
0300	Full scan	1500	Full scan
0330	Full scan	1530	Full scan
0400	Full scan	1600	Full scan
0430	Full scan	1630	Full scan
0500	Full scan	1700	Full scan
0530	Full scan	1730	Full scan
0600	Full scan	1800	Full scan
0630	Full scan	1830	Full scan
0700	Full scan	1900	Full scan
0730	Full scan, retrace to 300	1930	Full scan
0800	Scan to 1500, retrace to 300	2000	Full scan, retrace to 300
0815	Scan to 1500, retrace to 300	2030	Scan to 1500, retrace to 300
0830	Scan to 1500, retrace to 300	2045	Scan to 1500, retrace to 300
0845	Scan to 1500, retrace to 300	2100	Scan to 1500, retrace to North Limit
0900	Scan to 1500, retrace to North Limit	2130	Full scan
0930	Full scan	2200	Full scan
1000	Full scan	2230	Full scan
1030	Full scan	2300	Full scan
1100	Full scan	2330	Full scan
1130	Full scan		

Table 2.--GOES-1 FGGE VISSR operation schedule for June, July, and August 1979

TIME GMT	VISSR action	TIME GMT	VISSR action
0000	Full scan	0840	Scan to 1250, retrace to 450
0030	Full scan	0850	Scan to 1250, retrace to 450
0100	Full scan	0900	Scan to 1250, retrace to 450
0130	Full scan	0910	Scan to 1250, retrace to North Limit
0200	Full scan	0930	Full scan
0230	Full scan	1000	Full scan
0300	Full scan	1030	Full scan
0330	Full scan	1100	Full scan
0400	Full scan	1130	Full scan
0430	Full scan	1200	Full scan
0500	Full scan	1230	Full scan
0530	Full scan, retrace to 450	1300	Full scan
0600	Scan to 1250, retrace to 450	1330	Full scan
0610	Scan to 1250, retrace to 450	1400	Full scan
0620	Scan to 1250, retrace to 450	1430	Full scan
0630	Scan to 1250, retrace to 450	1500	Full scan
*0640	Scan to 1250, retrace to 450	1530	Full scan
*0650	Scan to 1250, retrace to 450	1600	Full scan
*0700	Scan to 1250, retrace to 450	1630	Full scan
*0710	Scan to 1250, retrace to 450	1700	Full scan
*0720	Scan to 1250, retrace to 450	1730	Full scan
		1800	Full scan
or alternatively for calibration		1830	Full scan
		1900	Full scan
*0640	Scan to 1250, retrace to North Limit	1930	Full scan
*0700	Scan to 1250, retrace to 450	2000	Full scan, retrace to 300
*0720	Scan to 1250, retrace to 450	2030	Scan to 1500, retrace to 300
0730	Scan to 1250, retrace to 450	2045	Scan to 1500, retrace to 300
0740	Scan to 1250, retrace to 450	2100	Scan to 1500, retrace to North Limit
0750	Scan to 1250, retrace to 450	2130	Full scan
0800	Scan to 1250, retrace to 450	2200	Full scan
0810	Scan to 1250, retrace to 450	2230	Full scan
0820	Scan to 1250, retrace to 450	2300	Full scan
0830	Scan to 1250, retrace to 450	2330	Full scan

and Laboratoire de Meteorologie Dynamique in France, calibration data for NOAA, and navigation data for the satellite attitude determination for SSEC. The digital cassettes are considered a Level I type archive, and digital computer tapes from these cassettes are available from SSEC. Log books of the GOES-1 operations and calibration during FGGE will be kept at SSEC in Madison, Wisconsin, after the completion of FGGE along with the digital image archive. The ODIS tapes were recycled during FGGE.

During FGGE there were several minor problems with the GOES-1 data, and one major problem -- the intermittent failure of the infrared sensor. The first failure of the infrared sensor occurred on 24 March 1979. The infrared sensor came back on and then failed again several times during FGGE. Table 3 lists the dates when the sensor was on or off. The failure of the sensor was characterized by a slow drift of the data toward either all black or all white. This drift would last for several hours. During this drift toward failure, the calibration was worthless. When the sensor came back on, the calibration appeared to be correct. This failure of the infrared sensor caused problems in tracking clouds, because the cloud height determination and the cirrus cloud tracking were heavily dependent on infrared data. The TIROS-N data were used at SSEC to measure cloud heights during times of the GOES-1 infrared failures. This processing will be described in a later section. The cause or a fix for the infrared failures was never determined, even though a considerable amount of effort by NESS, SSEC, and NASA was applied toward this problem.

There were several minor problems with the GOES-1 data. These were generally noted on the log sheets which accompany the archive. The period of December-February had a minor problem with dark segments being in the visible data. The period of mid-December to mid-January had repeated segments 8 pixels long on the visible data. During the spring eclipse period, the satellite was put in the analog sun pulse mode which caused a periodic image distortion of up to six visible pixels. The only minor problems which affected the wind determination efforts were the repeated segments and the analog sun pulse image wiggle. These problems added 3-4 m/sec to the random error of the cloud tracked vectors. All of the minor problems were corrected after they were discovered.

3. CLOUD TRACKING OPERATIONS AT SSEC

3.1 Operations Plan

The archive and ODIS tapes were shipped from Villafranca to the Space Science and Engineering Center at the University of Wisconsin. There the data were processed for cloud tracked winds which were then shipped to the Level II-b center in Sweden. The operations plan at SSEC is detailed in the U.S. FGGE Data Management Plan, Vol. 2, Annex 3.

SSEC produced three types of cloud track wind vectors during FGGE. The first type was a tropical high density wind set in the regions from 15°N to 15°S, utilizing two U.S. geostationary satellites (GOES-East and GOES-West). This wind set was referred to as the "Tropical wind set". The second was a macroscale wind set utilizing the full disk images from the geostationary satellite over the Indian Ocean. This data set was comparable

Table 3.--IR sensor functioning of Indian Ocean GOES during the FGGE period

Date	On	Off	Intermittent	Date	On	Off	Intermittent
<u>1978</u>				160-161		x	
335-365	x			162			x
<u>1979</u>				163-173	x		
001-057	x			174			x
058			x	175-176		x	
059-075	x (Only 7 visible channels)			177			x
076-082	x			178-180	x		
083			x	181			x
084-085		x		182-290		x	
086-089	x			291			x
090			x	292-296	x		
091-117		x		297			x
118			x	298-299		x	
119-125	x			300			x
126-128			x	301-304	x		
129-130	x			305			x
131-145		x		306-307		x	
146-151	x			308			x
152			x	309-311	x		
153	x			312			x
154			x	313-331	x		
155		x		332			x
156-158	x			333	x		
159			x	334			x

in coverage to the cloud wind sets produced operationally by NESS. This data set was referred to as the "Indian Ocean wind set". The Tropical wind set and Indian Ocean wind set were produced for the entire FGGE Operational Year. The third type of cloud track vectors, referred to as the "MONEX wind set" was a high-density wind set using images from the geostationary satellite over the Indian Ocean. The coverage was approximately 30°N to 20°S, depending upon synoptic conditions for a 100-day period beginning with 1 May 1979. The tropical wind set was measured at the 18 GMT synoptic time slot, the Indian Ocean set at 00 and 12 GMT (except when the infrared sensor failed when only the 12 GMT was available), and the MONEX winds at the 06 and 18 GMT time period (except when the infrared sensor failed when only the 06 GMT was available). The average daily number of winds produced for the different wind sets is as follows. For the tropical wind set, the average daily number of winds was approximately 1450. For the Indian Ocean wind set, the average daily number of winds during 1 December - 30 April 1979 was approximately 1350. Because of the numerous failures of the infrared sensor between 1 May - 30 November 1979, SSEC maximized its efforts to derive winds from visible images centered near 0900 GMT and so it is not possible to clearly separate the numbers of winds produced for the Indian Ocean and MONEX wind sets. Thus, the combined Indian Ocean wind sets averaged approximately 1700 winds during the period 1 May - 8 August. During the period 9 August - 30 November, the average daily number of winds for the Indian Ocean wind set was approximately 1250. A general description of cloud tracked winds, the processing, and the problems is contained in Mosher (1978).

3.2 Cloud Tracking

The cloud motions were measured on the McIDAS (Man-computer Interactive Data Access System) (Chatters and Suomi (1975), Smith (1975)). This is an image storage, display, and processing system consisting of data archive, data access, video display, operator console, and computer control sections. Central to the system is a computer which controls the display section, operator console, and computer peripherals. Data enter the system either from an antenna on the roof which receives the stretched SMS data, the archive tapes, or computer tapes such as the ODIS. The real time or archive ingestion of data is done by using a data interface box which converts the incoming visible and IR data into 8-bit bytes, averages the elements in a line to produce equivalent 1/2, 1, 1-1/2, 2, 3, and 4 mile resolution data, packs the data into 24-bit words, and then puts the data directly onto the digital disk. The Indian Ocean processing was done using 3-mile resolution data with 30 minutes between images. The Tropical data set was done using 2-mile data with 15 minutes between images except in areas of active convection where 1-mile data with 7-minute intervals were used. The MONEX data set used 2-mile, 15- (or 10-) minute data.

Using the McIDAS, it is possible by simple key-ins to enhance an image, magnify it, combine adjacent images into loops of any length, locate and track clouds, and display the results as a vector plot superimposed on the original image. Two independent signal systems allow double looping of infrared and visible images, with instant single key transfer from one to the other.

Tracking may be done by either of two primary methods: cursor tracking of the cloud to the nearest TV line and element (pixel tracking), and image match tracking of the cloud to better than TV line-element resolution (correlation tracking). Pixel tracking has been facilitated by the addition of a function called the velocity cursor. The operator positions a cursor over the cloud to be tracked using a joy stick. The velocity cursor function then automatically displaces the cursor from one picture to the next according to the position of a second joy stick. The velocity cursor can be used by itself for single pixel tracking, or it can be used in conjunction with the correlation tracking. Correlation tracking requires the operator to roughly track the cloud by placing the cloud within a box for each picture in a set. The computer then performs a correlation analysis to align the brightness field and "fine tune" the operator's tracking. Correlation tracking is the more accurate, but it requires well-defined clouds moving in a single layer flow pattern. Single pixel tracking using the velocity cursor can be invoked by the operator for tracking clouds in multi-layer flow patterns, or for matching the motion of a pattern if individual clouds cannot be tracked.

3.3 Image Alignment

Image alignment was done using a satellite navigation system, developed at Wisconsin by Phillips (1974), which models the satellite orbit and attitude and uses this information in the transformation from satellite to Earth coordinates and vice versa. The orbits used for the Indian Ocean data were those measured by ESA. The attitude of the satellite was determined from land mark measurements at Wisconsin. The accuracy of the navigation is generally better than a full resolution pixel for relative alignment between images, and several pixels of absolute location.

Cloud tracking was done using 3 images so that a single cloud motion can be measured twice as a quality control measure. The systematic difference between the velocity measured on the T_1T_2 sequence and that measured on the T_2T_3 sequence is a measure of the error due to the relative alignment of the images. For a sampling of data sets between January and July 1979, 53% had residuals differences of .5 m/sec or less; 90% had residuals differences of 1 m/sec or less; 5% had residuals differences greater than 2 m/sec.

3.4 Cloud Height Determination

Cloud heights were determined from the infrared temperatures and temperature profiles. When the infrared sensor failed, the TIROS-N sounding channels were used for height determination. This will be described in a later section.

The visible-infrared cloud height algorithm (Mosher, 1975) used visible data to determine optical thickness from which infrared emissivity and physical thickness can be inferred. At the beginning of FGGE, the derived infrared emissivity was used to recalculate the infrared temperature. The derived temperatures, however, showed sporadic gross errors. The recalculated infrared temperature portion of the cloud height algorithm was removed

in January 1979. The remaining algorithm had a two part decision tree. If the emissivity calculation showed the cloud to be a blackbody, an average temperature of the cloud was used. If the cloud was not a blackbody, the coldest infrared pixel was used. During the end-to-end test of the SOP-1, it was noted that the cloud tracked winds from SSEC were on the average colder than those of NESS for the tropical wind sets where there was overlapping coverage. An investigation of the differences was made using both height determination systems on the same clouds. This confirmed the differences. The SSEC's method averaged 1.5°C colder than NESS' method. The cloud height algorithm was changed from picking the coldest IR pixel to picking the coldest value in an infrared histogram which has more than two pixels in it (the NESS algorithm). This eliminated the differences. The revised algorithm was installed at SSEC during April 1979.

The work of Hasler, et al. (1977) has shown for trade cumulus that the wind at cloud base is most closely related to the drift of the cloud. The cloud height algorithm used the estimated cloud thickness derived from the optical thickness and put the wind level at the cloud base for clouds with bases below 850 mb. However, the temperature reported with the wind was that of the cloud top.

The temperature profile used for all of FGGE was the climatological profile described in Mosher (1975). The original FGGE plans called for using the NMC analysis for the profile, but a series of problems prevented the installation of the computer link to NMC until the end of FGGE. While the climatological profile works well in the tropical oceans, midlatitude regions with synoptic conditions of strong troughs or ridges can have height errors of up to 100 mb.

Cloud heights were either automatically determined with each wind measurement, or were manually assigned by the operator. The manual height assignment mode was generally used when there were multiple cloud levels, thin cirrus, or TIROS-N derived cloud heights. The manual height assignment method of Hubert (1975) was used in that a "representative" cloud height would be measured and this height would be assigned to a "fleet" of vectors from clouds in the general vicinity with similar motion characteristics. In the Indian Ocean data set, there were an average of approximately 18 vectors per fleet.

3.5 Cloud Selection

Not every cloud that appears to move is a valid tracer of winds. Gravity waves, orographic clouds, thunderstorm cores, etc. are not representative of the wind field. Thunderstorm outflow, sea breezes, etc., while being representative of mesoscale wind flow, are not representative of synoptic scale flow. The FGGE cloud trackers were meteorologists (with at least a B.S. degree) who had enough synoptic experience to recognize when flow patterns were associated with synoptic scale systems. In the training for FGGE, the cloud trackers were instructed to ignore flow patterns, such as thunderstorm upper level divergence, if it influenced an area smaller than 200 km square. If features such as cloud clusters in the tropics were present which had an influence radius larger than 200 km and were locally

divergent, the operators were instructed to measure at least four vectors around the system. If the operator could not measure vectors all the way around the system, he was instructed to measure only one vector which showed the large scale flow. The operators were trained to ignore features such as gravity waves and orographic clouds. They were told to concentrate on the meteorologically significant systems such as jets, storms, etc. They tried to distribute the vectors within the constraints of cloud availability to obtain reasonably uniform coverage. The operators were instructed to attempt to measure midlevel clouds, especially in the tropics. However, plots of the cloud winds show that there were generally not enough midlevel clouds available to adequately depict the midlevel circulation patterns.

3.6 Quality Control

The quality control procedures outlined in Appendix A of Volume 2, Annex 3 of the U.S. FGGE Data Management Plan were used except that overlays of conventional data measurements were not available. The operators did have fax maps of the NMC global analysis available for reference in the Indian Ocean processing. Three images in a sequence were always used in order to allow the cloud to be tracked twice and compared for consistency. If for some reason one of the three images at the scheduled times was unusable, the sequence time was shifted until a sequence of three could be obtained. The satellite images were sectorized into TV-sized areas for wind processing. For the Indian Ocean, the Earth's disc was divided into 16 sectors for processing. As the winds were measured, the vectors were displayed on the graphic overlay and edited when necessary. Figure 1a shows the visible image of a sector over India on 5 May 1979, 0930 GMT, and the measured low level wind vectors. Figure 1b shows the infrared image and the high-level flow of the same region.

3.7 Summer MONEX Wind Set

In addition to the normal FGGE Indian Ocean wind set, an enhanced wind set was produced during the summer MONEX period. The area of enhancement was from approximately 30°N to 20°S, 20°E to 95°E. The time period of enhancement started on 1 May 1979 and lasted for 100 days. The operational procedure of the MONEX enhancement was to measure the large scale flow using 3-mile data with half-hour time resolution. Then an enhanced wind set was produced using 2-mile data and 10-or 15-minute time resolution on the rapid scan images just prior to the normal wind images. The large scale vectors were displayed on the rapid scan images, and the enhancement was done by filling in the voids around the previously measured vectors. Since the large scale winds were measured generally on the 0930, 1000, and 1030 GMT images, they were included in the 12Z reporting period for FGGE. The rapid scan enhanced wind sets were generally at 0830, 0845, 0900 GMT or 0850, 0900, 0910 and were included in the 06 GMT reporting period. When the infrared channel was available, a similar situation occurred with the normal winds in the 00 GMT period and the MONEX winds in the 18 GMT period. Even though these MONEX and Indian Ocean wind sets were put in separate reporting periods, they should be considered as part of the same data set because there is less than an hour between them.

Figure 1a.--Visible sector over India on 5 May 1979 showing the low-level cloud wind field.

Figure 1b.--Infrared sector over India on 5 May 1979 showing the high-level cloud wind field.

3.8 TIROS-N Cloud Heights

The GOES-1 infrared sensors failed several times during FGGE (see Table 3 for dates). The infrared channel provides several functions. It allows tracking of clouds at night. It is very helpful in the detection and tracking of cirrus. Finally, it is used to obtain the heights of the cloud tracers.

Without the infrared sensor, it was impossible to obtain winds at night for the 0 GMT data set. During the daytime hours, there were several options available: guessing at the cloud heights (high or low as was done in the early days of cloud tracking with ATS), obtaining cloud height information from a different data source, or not processing the data.

The second option was chosen by obtaining cloud height information from the TIROS-N HIRS and microwave sounding channels. The cloud heights were obtained using the multispectral CO_2 absorption method of Menzel, et al. (1978). The cloud pressure is determined from the ratio of the deviations in cloud produced radiances and the corresponding clear air values for two or more spectral channels. The method works well for all types of clouds, including thin cirrus. The vertical resolution archived is roughly 50 millibars.

The operational procedure had the cloud tracker first process the TIROS-N orbits by identifying cloud features and measuring several heights for each of the major cloud features. These heights were stored in a file along with the location of the measurement. Next the GOES visible cloud tracking sequence was displayed. The TIROS-N cloud heights were plotted on the GOES images at the location of the measurement. Since there was a time difference of up to three hours between the overflight of the TIROS-N and the GOES sequence, the plotted cloud heights did not always fall on top of the cloud. The cloud tracking meteorologist would make a subjective judgment on what cloud heights went with what clouds.

A short study was done to see if the TIROS-N cloud heights differed significantly from the normal GOES heights. For one day (6 May 1979) when the TIROS-N data were available and the infrared sensor was working correctly, the normal procedure of selecting clouds on the TIROS-N data and displaying the results on the GOES images was followed. The operator selected the cloud to which he would have assigned the TIROS height and then measured the cloud height using the GOES infrared data. The mean difference between the two data sets was 13 millibars (TIROS being lower) with a standard deviation of 66 millibars. The sample size was 87 cases distributed over the Indian Ocean. The TIROS cloud top temperature was an average of 0.8°C warmer with a standard deviation of 7.8°C.

4. SUMMARY AND CONCLUSIONS

The geostationary satellite coverage of the Indian Ocean during FGGE was successful. In less than a year a joint effort by NOAA and ESA was able to configure a ground station in Spain for operation by ESA. The GOES-1 was moved over the Indian Ocean. SSEC at the University of Wisconsin provided the archive and data processing support for the cloud tracking operations for the

FGGE Level II-b data set. The full resolution digital image archive of the entire FGGE year of the GOES-Indian Ocean, GOES-East, and GOES-West is available at SSEC. Computer tapes from this archive are available from SSEC.

The only major problem with the GOES-Indian Ocean program was the intermittent failure of the infrared sensor after March 24, 1979. A total of 159 days have no infrared data and an additional 18 days have only partial coverage during the day. The infrared sensor failed on eleven different occasions. During the times of no infrared coverage, the cloud heights were obtained from TIROS-N data and the cloud tracking was done on the visible images. Analysis of TIROS-N cloud height process showed no significant bias in height assignment as compared to the infrared derived cloud heights. The only noticeable deficiency of the cloud wind data set without the infrared data was a tendency for the jet cores to be poorly defined and the wind maxima to be missed occasionally.

The FGGE Level II-b data set for the Indian Ocean contains over 510,000 cloud tracked vectors. An additional 529,000 vectors were generated at SSEC as part of the GOES-East and West tropical data set.

The GOES Indian Ocean program depended heavily on international and interagency cooperation. The successful completion of the program in spite of short lead times and equipment failures speaks highly of the many people all over the world involved with the program.

CHAPTER 4

SOUTHERN HEMISPHERE DRIFTING BUOYS

By
E. Kerut (NOAA/NDBO)

1. INTRODUCTION

This chapter summarizes the performance of the 64 U.S. drifting buoys deployed in the Southern Oceans during the Global Weather Experiment. Forty-six buoys were deployed by ship and 18 buoys were deployed by aircraft as part of the drifting buoy array established during the experiment. An examination of the buoy performance indicated that approximately 56 percent of the buoys were operational after six months, and 40 percent after one year.

As part of the U.S. drifting buoy development program, extensive testing was performed to verify system performance prior to the start of the experiment. End-to-end systems tests were performed to establish system interface compatibility and to determine if corrections to production buoys were needed prior to buoy deployment during the experiment. Data quality analyses were performed on systems prior to and during buoy deployment periods.

An extensive test and evaluation program preceded the deployment of operational buoys. Pre-FGGE system end-to-end testing was conducted to uncover system level problems before the shipment of production buoys from the manufacturer for deployment in the experiment. Predeployment and deployment testing was performed to evaluate the quality of the data from each of the buoys being deployed. A description of each test and the evaluation results follows. Finally, buoy performance during the First and Second Special Observing Periods (SOPs) is summarized.

Central to the drifting buoy system is the utilization of the polar orbiting ARGOS satellite system for data telemetry and position location. Operated by the French Centre Nationale d'Etudes Spatiales (CNES), the ARGOS Data Collection System (DCS) provides a means to locate and/or collect data from fixed platforms and moving buoy and balloon platforms. Buoy data were acquired through ARGOS when the TIROS-N and NOAA-6 satellites were in view. All data were collected at control data acquisition stations in Gilmore, Alaska, and Wallops Island, Virginia; and then via landlines transmitted to the spacecraft operational control center in Suitland, Maryland, for preliminary processing. The data were then transmitted to the CNES in Toulouse for processing by Service ARGOS. Processed data were then disseminated as appropriate. Meteorological data was disseminated worldwide on the Global Telecommunications Service (GTS).

2. PRE-FGGE TEST AND EVALUATION

The primary objective of pre-FGGE test and evaluation programs was to conduct end-to-end system tests prior to the shipment of production buoys from the manufacturer. The tests were performed on development/prototype buoys in an effort to determine difficulties or problems attributable to buoy components/subsystems that could still be corrected on the production systems. The tests included system checkout of the drifting buoys, satellite, communications links, data processing, procedural matters, and the training of personnel. Buoy sensor and position data were processed by Service ARGOS in Toulouse, France, and the results compared with data from a ground-truth system developed by the NOAA Data Buoy Office (NDBO).

Table 1.--Statistics on buoy sensor performance for barometric pressure and water temperature.

	BUOY 1641	BUOY 1642	BUOY 1643	OVERALL
Barometric Pressure (mb)				
Mean Difference Between Buoy and Ground Truth	0.34	0.87	0.83	0.73
Standard Deviation	0.48	0.43	0.46	0.46
No. Observations	66	107	115	288
Water Temperature (°C)				
Mean Difference Between Buoy and Ground Truth	0.15	0.15	0.40	0.25
Standard Deviation	0.32	0.17	0.17	0.21
No. Observations	49	106	107	262

Three prototype buoys were evaluated during a six-week intensive test period. The following buoy performance characteristics were measured and evaluated:

- o Performance and accuracy of the two primary meteorological sensors (barometric pressure and sea surface temperature)
- o Performance and accuracy of the position location system
- o Number of actual and good data transmissions per day
- o Total elapsed time for various types of data received from Service ARGOS and processed or analyzed by NDBO.

2.1 Buoy Sensor Performance

Buoy data received through the TIROS-N satellite were compared with ground-truth data. The buoys under test were equipped with Paroscientific barometric pressure sensors with a specified accuracy of ± 1 mb with a range of 900 to 1050 mb. The digital resolution (one count) was 0.15 mb. The ground-truth pressure system included three Rosemount transducers with a specified accuracy of ± 0.6 mb over the range of 900 to 1050 mb. The ground-truth pressure sensors were averaged to provide a more accurate reference. The statistics on buoy pressure sensor performance are summarized in Table 1. All three buoys showed a positive mean difference when compared with the ground-truth reference standard. The range of pressures measured during the tests was from 1004.2 to to 1032.2 mb.

The post-calibration check of the ground-truth barometers indicated that the ground-truth pressures averaged 0.8 mb low over the range of pressures measured. The test buoy pressures fell within the specified accuracy with the ground-truth correction taken into account.

The buoy water temperature sensors were Yellow Springs Instruments thermistors with a specified accuracy of ± 1°C with a range of -5° to +35°C. The digital resolution (one count) was 0.16°C. The ground-truth temperature sensor system included several Action Instruments platinum-resistance transducers with a specified accuracy of ± 0.4°C over the range of 0° to 30°C. The ground-truth sensor readings were averaged to provide an accurate temperature reference. The buoy water temperature measurements statistics are summarized in Table 1. The data fell within the specified accuracy range.

2.2 Buoy Location System Performance

The buoy location system performance was evaluated in a controlled test. Five buoys were moored at fixed locations. Data were collected from the buoys starting two weeks after the launch of TIROS-N on October 13, 1978, and continuing through December 12, 1978. During this period, 224 position fixes were selected from the DISPOSE file obtained from Service ARGOS. The location data can be summarized as follows:

- The mean radial error for all fixes from the actual location was 0.26 km.

- The standard deviation of mean radial error was 0.16 km.

- The largest radial error was 2.15 km.

- More than 96 percent of all position fixes were within 0.72 km.

The results of the controlled tests indicated that the position-fixing system is accurate, reliable, and virtually error-free. The accuracy and reliability of the ARGOS location system well exceeded all initial estimates. It proved to be reliable, accurate, and suitable for use whenever accuracy to within 1 km was required.

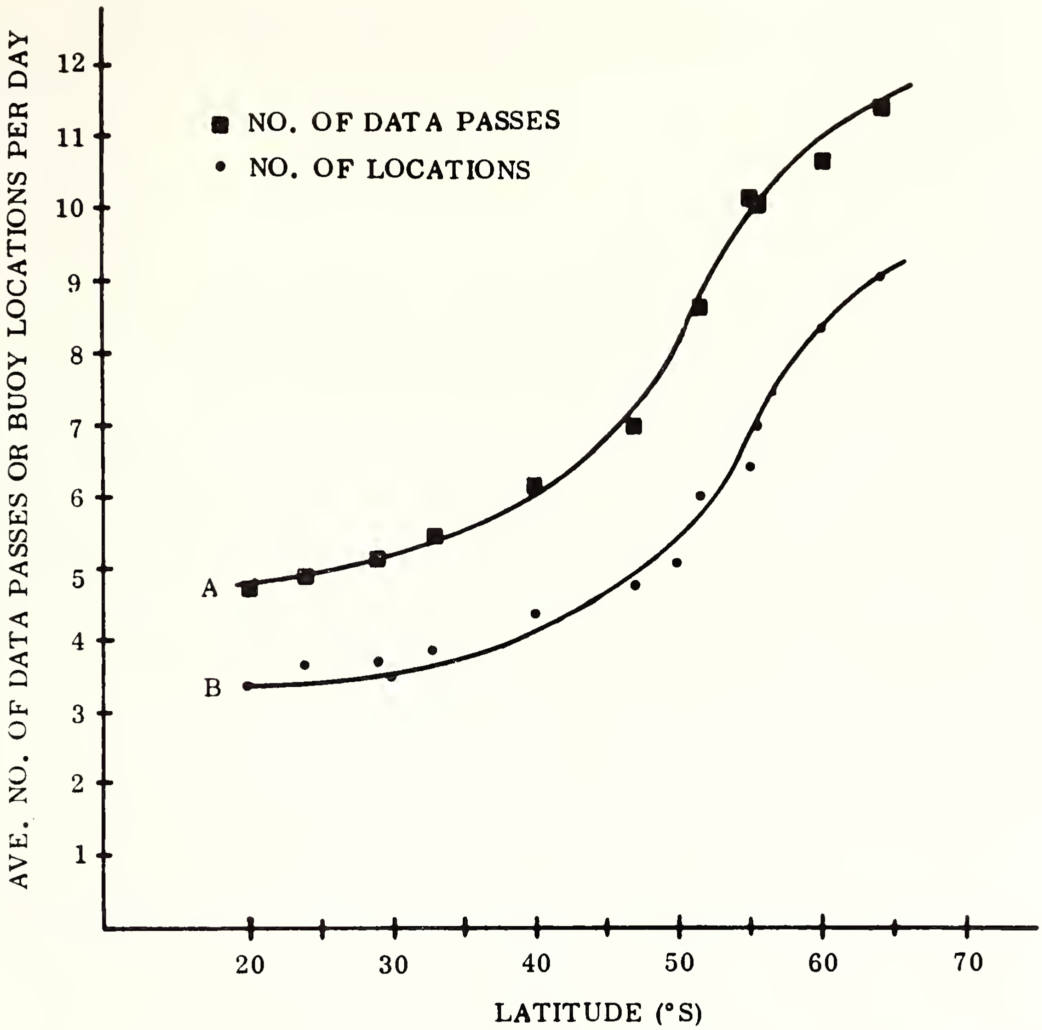
In the effort to effectively evaluate the overall system performance early in the experiment, a large data set was collected and analyzed. Statistics on the number of position fixes were analyzed. Time delays in obtaining, transmitting, and processing buoy data were analyzed statistically to provide estimates of minimum and maximum delays for data to be updated on the computer files of Service ARGOS. Estimates of delays in accessing data from the files were also made using remote terminals.

2.3 Data and Buoy Location Passes

A simplified approximation of the average number of satellite passes per day in view of a buoy is shown in Figure 1. The number of passes depends on the latitude of the buoy and the minimum elevation angle at which the satellite can receive the buoy data.

Using operational U.S. FGGE buoy data, the mean number and standard deviation of both good data passes and buoy locations per day were calculated as a function of latitude over a one-month period for buoys located from 20°S to 65°S latitude. These data are shown in Figure 1. Curve A shows the increase in the average number of good data passes per day as the latitude increases. Comparison with the curves in Figure 2 indicates that data receptions appear to be obtained for buoy elevation angles as low as zero degrees. Curve B in Figure 1 shows the average number of good buoy locations per day as a function of buoy latitude. This curve follows curve A very closely. The buoys transmitted every 51.36 seconds, and at least three good transmissions are required to calculate buoy location.

Figure 3 presents the same buoy location data in a different form. Curve C shows the percentage of data passes that resulted in a good buoy location. This percentage (70 percent) is independent of buoy latitude. Curve D shows the percentage of satellite orbits per day that resulted in a good buoy location. This curve is similar to curve B of Figure 2.



LATITUDE	MEAN NO. OF DATA PASSES/DAY	STANDARD DEVIATION	MEAN NO. OF BUOY LOCATIONS/DAY	STANDARD DEVIATION
20°	4.74	0.94	3.37	0.97
24° S	4.89	0.97	3.63	0.49
29° S	5.11	0.89	3.67	0.68
30° S	5.14	0.79	3.52	0.70
33° S	5.48	0.70	3.85	0.82
40° S	6.19	0.56	4.37	0.84
47° S	7.00	1.00	4.74	0.71
50° S	8.22	0.58	5.07	1.04
51.5° S	8.62	0.79	6.00	1.07
55° S	10.11	0.32	6.41	1.34
55.5° S	10.07	0.47	7.00	1.07
60° S	10.63	0.56	8.30	1.49
64° S	11.37	0.63	9.00	1.07

Figure 1.--Average number of data passes and buoy locations per day as a function of latitude.

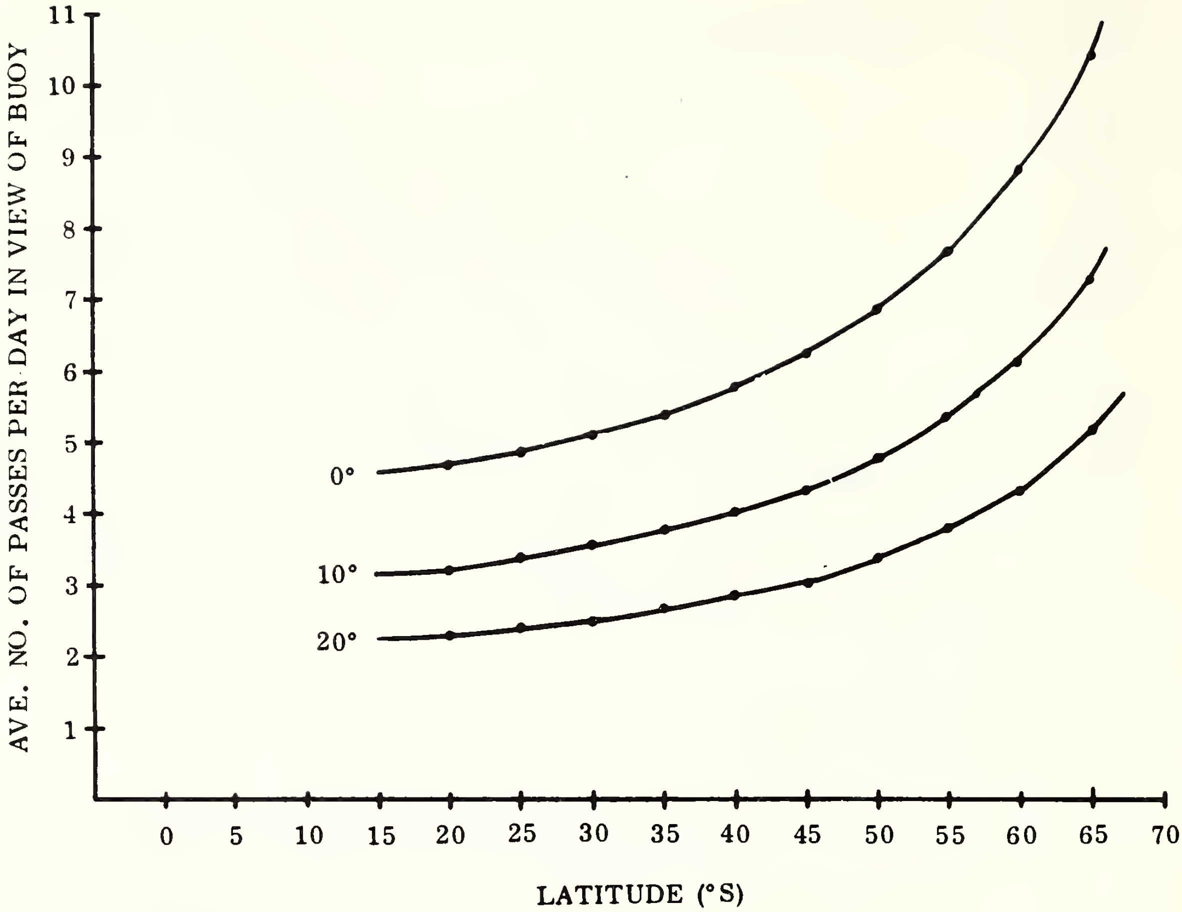
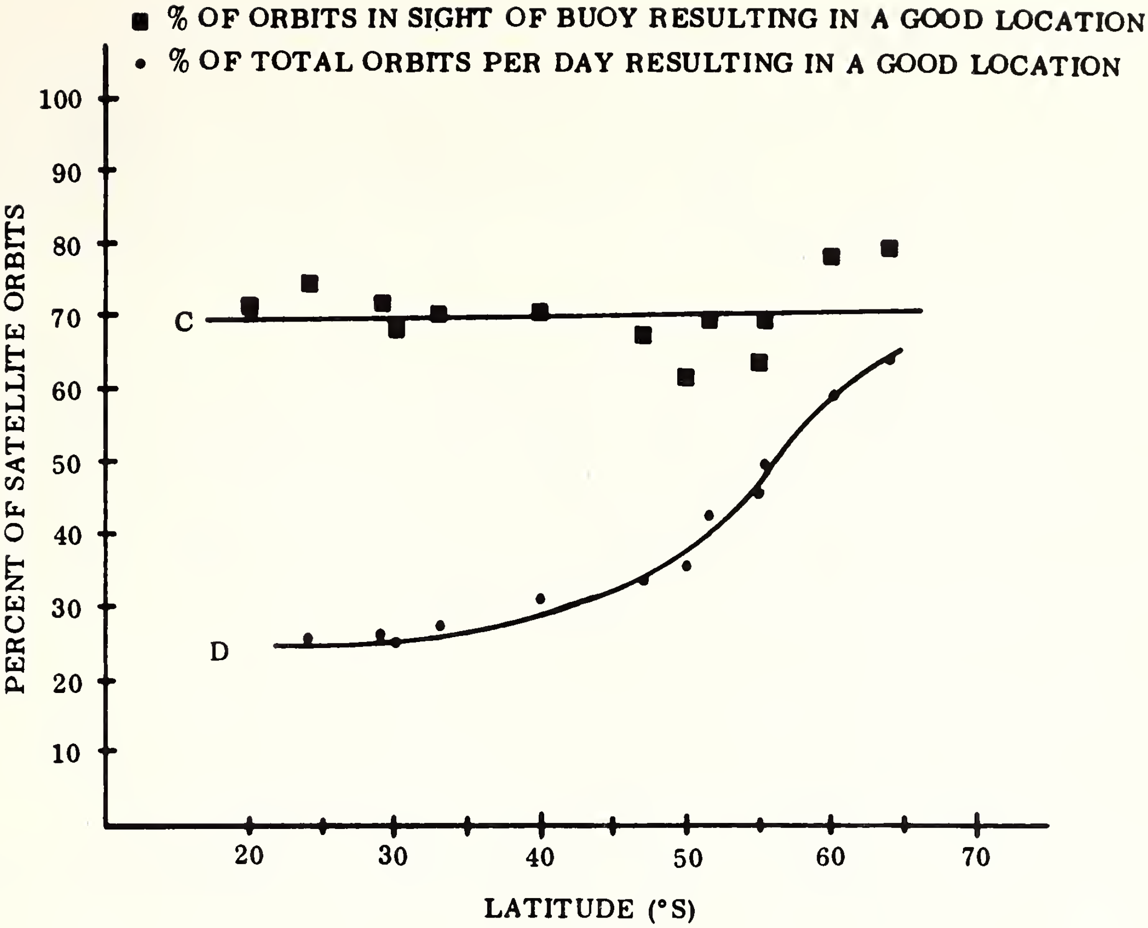


Figure 2.--Average number of satellite passes per day in view of a buoy at a given latitude for various angles above the horizon.



LATITUDE	PERCENT OF TOTAL DAILY ORBITS	PERCENT OF ORBITS IN SIGHT OF TRANSMITTER
20° S	24.0	71.1
24° S	25.8	74.2
29° S	26.1	71.8
30° S	25.0	68.4
33° S	27.4	70.3
40° S	31.1	70.6
47° S	33.7	67.7
50° S	36.0	61.7
51.5° S	42.6	69.6
55° S	45.6	63.4
55.5° S	49.8	69.5
60° S	59.0	78.1
64° S	64.0	79.2

Figure 3.--Percentage of satellite orbits resulting in a good buoy location as a function of latitude.

2.4 Data Transmission Per Pass

Service ARGOS data from the DISPOSE file were analyzed to determine transmission statistics on all passes for which buoy data were obtained. The average number of transmissions per orbit for passes over five different buoys at various latitudes were calculated, and the results are summarized in Table 2. The overall average was calculated to be 13.43 transmissions per orbit. The maximum number of transmissions received on any sample orbit was 19.

2.5 Time Delays in Data Transmission and Processing

The U.S. FGGE buoy data transmissions stored in the Service ARGOS AJOUR file were analyzed to determine typical maximum and minimum delays in obtaining the most recent buoy data. The AJOUR file indicated when it was last updated, and that time was compared with the time that each buoy transmitted data. Also, the dead time in orbit from a particular location was calculated to estimate the average time required to transfer data from the satellite to Service ARGOS and to update the AJOUR file. Early results of this analysis for a one-satellite system were as follows:

- o Maximum time delay - 10.35 hours
- o Average of the maximum time delays - 8.46 hours
- o Minimum time delay - 1.27 hours
- o Average time for data to be transferred from the satellite to Service ARGOS and to update AJOUR file (no dead time in orbit) - 80 minutes.

3. PREDEPLOYMENT AND DEPLOYMENT DATA QUALITY ANALYSIS

The objective of this effort was to evaluate the performance of each of the U.S. FGGE drifting buoys deployed in the southern Pacific Ocean during the November 1978 to February 1979 time period, extending from buoy activation to just after launch. Forty-six buoys were deployed by five ships. Buoy data obtained from Service ARGOS were evaluated daily and compared with ground-truth data reported by each ship.

The evaluation period started at the time each ship left port and continued until after the buoy had been launched and ground-truth data had been compared with buoy data received via the satellite. Shipboard ground-truth data received via radio communication links were compared and evaluated daily with buoy data obtained from Service ARGOS. If buoy sensor data were questionable or out of tolerance, NDBO management and the U.S. FGGE Project Office were notified immediately so that a decision could be made whether to deploy the buoy, substitute another buoy, or forego deploying a buoy at that location. Also, in certain instances, instructions concerning buoy operation or maintenance were sent to the ships.

Table 2.--Average number of transmissions per orbit for data passes over buoys at various locations.

BUOY ID	LATITUDE	AVERAGE NUMBER OF TRANSMISSIONS PER ORBIT	STANDARD DEVIATION	NUMBER OF ORBITS SAMPLED
1602	44°S	13.07	4.19	100
1608	22°S	13.76	3.97	50
1611	66°S	14.24	4.08	102
1621	45°S	12.93	4.58	60
1634	32°S	13.07	4.30	96
Overall		13.43	4.36	403

Each ship was requested to activate its buoys and to provide an update of the launch schedule by buoy ID and location well in advance of the time that daily buoy checkout reports were required. There was some reluctance on the part of the ships to activate the buoys, since they transmitted at a frequency of 401.65 MHz, which is slightly above the frequency of some of the shipboard navigation equipment. However, tests conducted by NDBO did not show an interference problem. Typically, several messages were sent to and received from each ship before the message procedure became routine. Messages were transmitted and received over the AUTODIM circuits using the Naval Oceanographic Office (NAVOCEANO) Communications Center located at the National Space Technology Laboratories (NSTL) near Bay St. Louis, Mississippi.

Buoy data were obtained by accessing the computer at Service ARGOS. Calibration tables and other data had been previously sent to Service ARGOS. The system periodically received satellite data and updated the AJOUR file with the latest buoy data. The Telex system was used as the primary means of accessing the AJOUR file. In most instances, this file was accessed at least once daily.

The overall data flows are shown in Figure 4. Note that there are two completely separate flows for the data. The ground-truth data from each of the ships go through radio and hardwire links to the U.S. FGGE Project Office, with an information copy going to NDBO. The buoy data are stored in a tape recorder on the satellite, dumped to one of the satellite ground Control and Data Acquisition (CDA) stations, and transmitted to the Data Processing and Services System (DPSS) at the National Environmental Satellite Service (NOAA/NESS) and then Service ARGOS, where the data are processed. The latest data are stored in the AJOUR file, which is accessed by means of a dial-up terminal. In order to time-correlate the ground-truth and buoy data, ground-truth data were taken by the ships at the same time that buoy data were being received by the satellite. In addition, the AJOUR file was accessed and the buoy data obtained before the buoy data from the next satellite pass were used to update the file.

The mean and standard deviation of the buoy-measured barometric pressures and sea surface temperatures were calculated daily for all buoys on board each ship. These statistics were compared with the ground-truth data. Typically, there was better correlation among the buoy sensors than between the buoy sensor mean and the ground truth. As buoys were launched, fewer remained on the ship and more emphasis had to be placed on the ground truth and analyzing the data. Daily verbal and weekly written reports were provided to NDBO and the U.S. FGGE Project Office.

Ground-truth pressure and temperature data were taken by ship personnel to coincide with the closest morning and afternoon local satellite passes. Equatorial crossing time and longitude were provided by NOAA/NESS for each satellite orbit. Planned and updated buoy launch location and time data were requested and obtained from each ship. Using the NOAA satellite and buoy launch data, equatorial crossing time and longitude for the morning (descending) and afternoon (ascending) orbits that passed closest to the ship were determined and the data sent to each ship. Each ship determined the time

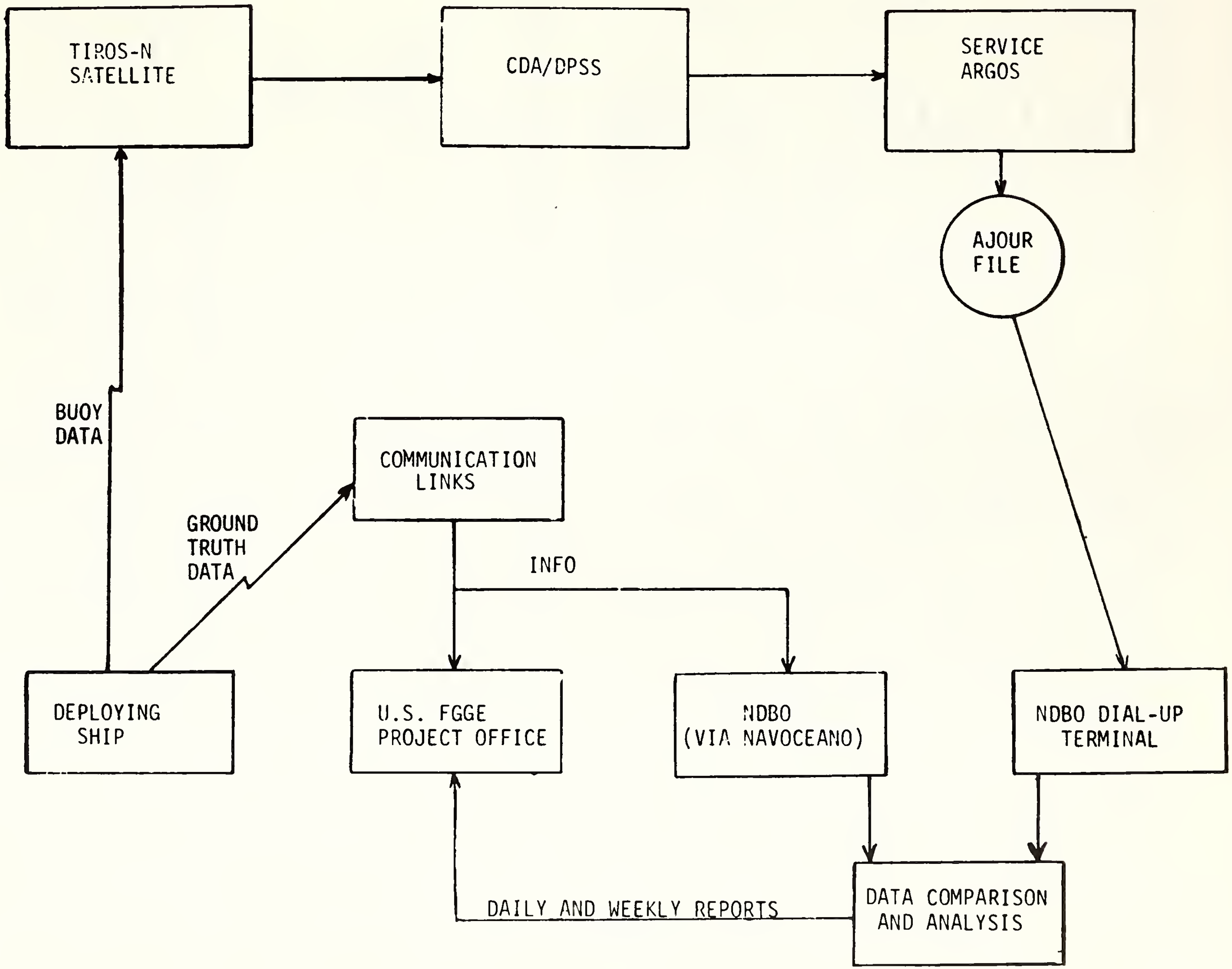


Figure 4.--Pre-deployment - primary data flows.

correction for its location. Ground-truth data were taken at this time and at 30 minutes prior to and after this time. Ground-truth data were also taken 3 hours prior to launch, at launch, and at 1-hour intervals for 9 hours after launch.

The procedures and steps required for the data analysis evolved during the program. The steps that were followed varied some from ship to ship, but in general followed the flow shown in Figure 5. Procedures were followed for monitoring buoys on a daily basis and during the launch sequence. Each ship was requested to provide the buoy deployment schedules, which also indicated which buoy (by Service ARGOS ID) was to be deployed at each position. Each ship was also requested to activate all of its buoys shortly after the ship left port. The AJOUR file at Service ARGOS was accessed daily and all buoy data that had been updated since the last update were obtained. A detailed data report from each ship was prepared which evaluated sensor performance by calculating the mean and standard deviation of all sensors that were within tolerance. Since the sensor data from each buoy on a ship were usually collected within minutes of each other, it was relatively easy to evaluate the data. These detailed data reports from each ship were compared with FGGE buoy checkout status reports which were received daily from each ship. If a problem was found, it was brought to the attention of NDBO and the U.S. FGGE Project Office and appropriate action taken. Similarly, FGGE buoy deployment status reports prepared by each ship following the launch of each buoy were compared with the appropriate data from the AJOUR file and the results analyzed. This analysis and the day-to-day tracking of the sensors were used to determine whether the buoy was operational at launch and whether to put the sensor messages in DRIBU code format on the Global Telecommunications System (GTS) for distribution.

The predeployment performance of FGGE buoy barometric pressure and sea surface temperature sensors were expected to meet or exceed the following standards during the predeployment analysis:

Physical Parameter	Range	Resolution	Mean	Standard Deviation
Barometric Pressure	900 to 1050 mb	0.15 mb	$\pm$ 1 mb	0.6 mb
Water Temperature	-5° to +35°C	0.16°C	$\pm$ 1°C	0.5°C

Redundancy of the received data permitted the detection of most random and burst errors in the overall end-to-end system, which included the satellite processing, communications links, and the ground-truth processing. Differences between the standard and the measured pressures were less than 1 mb, and averaged 0.6 mb over the range of pressures tested. The sea surface temperature data were checked while the buoys were on deck prior to deployment. Due to varying amounts of solar and other radiation and different physical locations on deck, the sea surface temperature sensor values varied as much as 2°C. Differences between sensor values and ground truth were as much as 3°C.

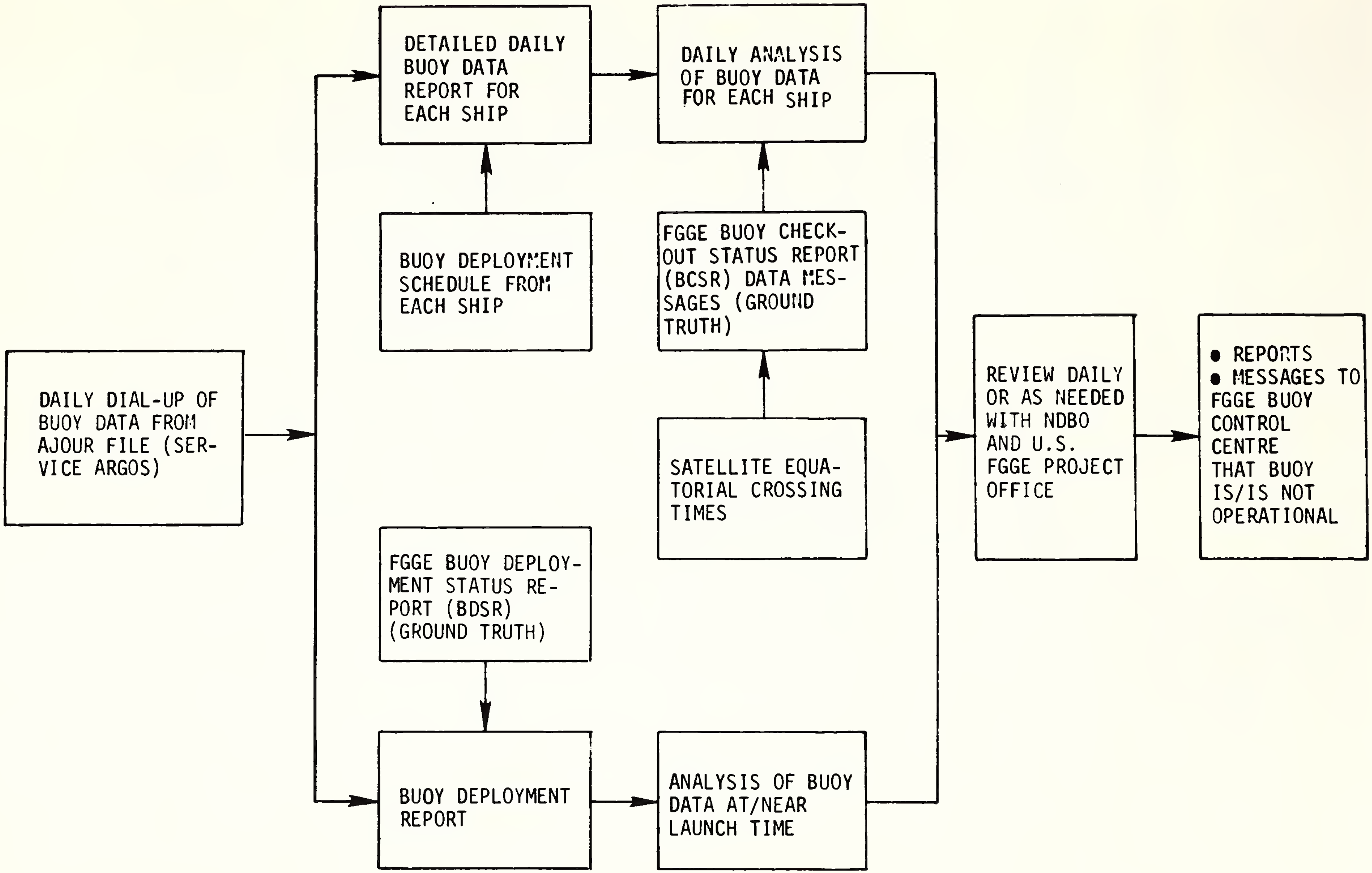


Figure 5.--Procedure and steps - data analysis.

After the buoys on a ship had been activated for several days, the differences in pressure between the individual buoys and the average of three or more buoys sampled at the same time were determined. If this difference was greater than 1 mb for a particular buoy, the sensor data were declared out of limits. A similar procedure was followed for the temperature, except that a wider tolerance was used and the temperatures were monitored over a longer period of time.

The calculated averages of the deviation of the good sensors from the mean of the sensor values for each satellite pass are listed below for each ship:

Ship	Average Pressure Standard Deviation (mb)	Average Temperature Standard Deviation (°C)
ORCADAS	0.5	1.3
POLAR STAR	0.3	0.7
ACUSHNET	0.5	1.1
MAUMEE	0.4	1.5
BLAND	0.4	0.4

There was good pressure correlation. The temperature correlation was poor for the reasons described previously.

4. PERFORMANCE EVALUATION FOR FIRST AND SECOND SPECIAL OBSERVING PERIODS (SOP I AND SOP II)

As part of the FGGE SOP I and II, 64 NDBO drifting buoys were deployed in the Southern Oceans. Forty-six were launched by ship and 18 were launched by aircraft. The purpose of the additional air-launched buoys was to reestablish the buoy network in preparation for the second Special Observing Period. After launch, the buoys were monitored daily, using the World Meteorological Organization DRIBU messages and other available data. The DRIBU messages were processed at NDBO on a weekly basis in order to edit the data, calculate performance statistics, and provide a summary report on overall network performance. Buoy positions as shown in Figure 6 were plotted on a weekly basis on a polar chart of the Southern Hemisphere. DISPOSE file listings for the U.S. FGGE buoys were obtained from Service ARGOS to provide additional data for buoy failure analysis. Additional information on buoy sensor performance was obtained by comparing buoy data with historical statistical data and synoptic maps of pressure and sea surface temperature obtained from the Bureau of Meteorology, Melbourne, Australia, and from the National Weather Service, National Meteorological Center, Suitland, Maryland.

Weekly and monthly summary reports were prepared for engineering and management evaluation of buoy performance. A typical report is shown in Figure 7 for the period January 5, 1979, to March 5, 1979. The mean, standard deviation, maximum and minimum values for the buoy daily drift velocity, barometric pressure, and sea surface temperature are plotted. The last reported buoy position and battery voltage are also reported. Buoy sensor, position fix, and network performance are computed for all the operational buoys during the report period.

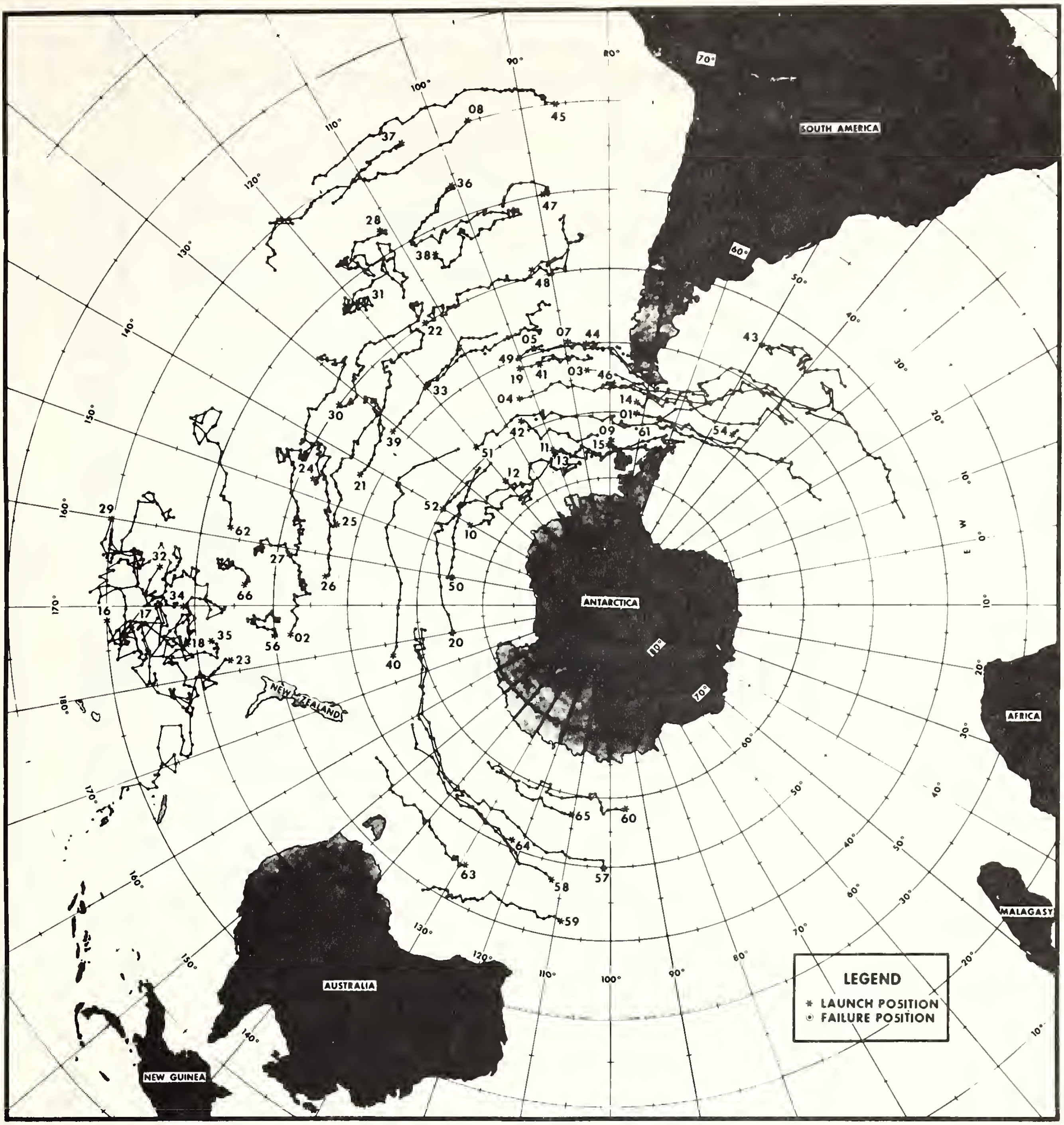


Figure 6.--U.S. FGGE drifting buoy tracks as of November 5, 1979.

OPERATIONAL FGGE DRIFTING BUOY SUMMARY
PERIOD: JAN. 5, 1979 - MAR. 5, 1979

BUOY ID DRIBU/SA	DEPLOYED MODYYR	FAILED MODYYR	POSITION LAT(S)	LONG(W)	DAILY DRIFT-KNOTS MEAN	STD.	MAX.	MIN	BATT VOLT	BAROMETRIC PRESSURE - MBAR MEAN	STD.	MAX.	MIN	SEA SURF TEMP - DEG MEAN	STD.	MAX.	MIN	NO OBS
54601/1601	121178		60.7	50.1	.44	.27	1.32	.03	16.2	F	F	F	F	.7	.42	1.5	-.1	94
54602/1602	121878		44.1	166.9	.49	.25	1.25	.06	17.4	1013.0	6.8	1028.1	994.9	16.8	.77	18.1	15.1	163
54603/1603	112878		53.8	57.4	.85	.64	4.19	.05	15.3	995.4	8.9	1012.6	977.7	7.0	.77	8.7	5.0	168
54604/1604	120478		56.3	75.3	.57	.34	2.76	.08	16.0	991.0	9.2	1013.1	972.2	7.4	.27	8.0	6.8	169
54605/1605	120178		55.9	67.3	.66	.51	3.31	.03	15.9	995.9	6.3	1011.8	978.2	9.7	.85	11.7	7.0	161
54607/1607	112278		54.8	71.4	.75	.33	1.46	.02	15.9	999.4	9.0	1015.6	975.1	8.2	1.65	11.5	3.0	142
54608/1608	011379		22.2	105.0	.45	.17	1.02	.12	16.9	1016.1	2.5	1022.1	1010.6	25.8	.33	27.2	24.9	67
54609/1609	120978		67.2	77.4	.41	.21	1.03	.06	16.2	984.8	9.9	1006.6	963.0	.6	.47	1.8	-.1	172
54610/1610	020279		66.4	135.5	.38	.19	.81	.02	16.8	981.1	9.6	996.3	952.7	.7	.22	1.1	.3	67
54611/1611	120678		64.9	89.6	.43	.25	1.74	.06	16.0	981.8	10.5	1001.0	952.5	.6	.35	1.2	-.3	169
54612/1612	020379		66.5	116.5	.17	.00	.17	.17	17.1	993.9	2.0	995.3	992.5	2.0	.00	2.0	2.0	2
54613/1613	020479		64.7	97.8	.41	.00	.41	.41	16.8	996.2	4.5	999.4	993.0	2.1	.00	2.1	2.1	3
54614/1614	112478		50.1	43.8	.59	.42	3.02	.04	15.7	1004.5	8.4	1023.6	977.7	6.6	.58	8.0	5.5	168
54615/1615	020679		65.1	78.1	.53	.24	1.16	.13	17.4	982.6	11.8	1008.6	964.8	1.8	.33	2.3	1.2	65
54616/1616	121478		26.0	170.1	.67	.40	2.28	.05	16.3	1009.6	3.8	1017.3	1000.1	26.7	.78	28.4	25.6	145
54617/1617	121478		26.9	-170.4	.65	.35	1.63	.05	16.2	1012.3	4.4	1019.6	997.5	24.8	.48	25.9	23.6	123
54618/1618	121578		28.8	175.7	.52	.29	2.45	.03	16.6	1013.1	4.1	1021.1	1004.8	23.9	.87	25.8	22.5	142
54619/1619	120278	011379	51.6	90.4	.52	.20	1.03	.22	16.3	988.3	9.4	1004.6	977.9	7.8	.13	8.0	7.5	22
54620/1620	020379		63.9	170.1	.59	.29	1.27	.03	16.5	982.1	11.5	1002.1	966.5	1.6	.10	1.7	1.5	65
54621/1621	010379		45.0	129.9	.52	.41	3.79	.07	16.3	1013.8	10.1	1031.3	985.9	13.2	.42	14.0	12.2	138
54622/1622	010879		40.2	179.9	.42	.23	1.37	.06	16.8	1018.6	7.1	1029.8	994.2	17.1	.72	18.6	15.6	109
54623/1623	121678		30.2	179.8	.48	.35	2.46	.05	16.8	1015.3	4.1	1022.8	1000.6	23.1	.99	24.7	20.5	137
54624/1624	121378		41.2	142.0	.47	.31	2.02	.06	16.3	1015.9	9.8	1032.1	986.7	17.6	.45	19.1	16.6	153
54625/1625	010179		45.7	147.3	.48	.30	2.47	.04	16.9	1012.8	9.1	1032.8	994.9	14.8	.41	16.6	14.1	161
54626/1626	123178		46.4	153.8	.52	.38	3.56	.09	16.8	1012.3	8.8	1031.3	994.6	14.9	.56	16.1	13.8	163
54627/1627	121578		42.3	156.3	.39	.28	2.63	.07	16.3	1016.6	8.2	1031.8	996.8	17.4	.53	19.7	16.1	161
54628/1628	120678		30.5	116.1	.46	.19	.95	.09	16.5	1016.7	2.8	1021.8	1010.3	24.8	.50	26.0	23.6	97
54629/1629	012279	012979	19.9	160.0	M	M	M	M	17.5	1012.3	.0	1012.3	1012.3	28.9	.00	28.9	28.9	2
54630/1630	121178		39.2	128.1	.44	.26	1.53	.08	16.5	1018.0	8.2	1034.3	987.3	17.7	.39	18.7	16.8	140
54631/1631	120878		33.1	119.4	.58	.22	1.49	.10	16.0	1019.3	4.8	1026.8	1007.0	22.3	.62	23.5	20.7	123
54632/1632	012379		24.9	168.7	.64	.39	2.73	.06	16.8	1013.2	3.6	1017.1	992.8	26.2	1.03	28.1	23.9	87
54633/1633	010679		46.2	109.9	.38	.19	.77	.05	16.5	1010.9	10.1	1028.3	983.3	11.4	.37	12.3	10.5	125
54634/1634	012479		31.7	159.3	.43	.19	1.01	.08	16.9	1015.3	4.3	1023.3	1002.1	24.0	.50	25.2	22.9	87
54635/1635	012479		32.6	166.9	.43	.26	1.39	.06	16.9	1016.6	4.2	1023.8	1006.3	22.6	.56	24.4	21.7	82
54636/1636	011279		28.6	105.0	.37	.19	.97	.07	16.8	1019.0	2.8	1023.1	1010.8	25.5	.38	26.6	24.8	90
54637/1637	120278	030579	21.9	115.0	.37	.16	1.09	.10	16.5	1014.9	2.4	1019.3	1004.6	26.3	.56	28.0	24.8	115
54638/1638	011079		34.8	103.9	.37	.22	1.17	.06	16.8	1020.2	5.3	1027.1	1002.3	21.4	.29	22.0	20.9	98
54640/1640	020279		57.5	168.6	.59	.26	1.38	.12	16.8	996.1	11.1	1011.8	961.6	7.0	.51	9.6	6.3	65
54645/1645	010279		18.2	86.6	.20	.15	.86	.05	16.3	1014.5	1.2	1016.8	1011.6	23.2	.23	23.9	22.8	110
54647/1647	010479		28.1	92.7	.41	.40	2.80	.04	13.[illegible]	1017.4	3.0	1023.3	1010.6	22.3	.59	23.7	20.9	115
54648/1648	010579		36.2	86.2	.54	.30	1.81	.07	12.9	1019.0	7.1	1035.8	997.9	17.5	.92	19.5	15.9	119
54649/1649	010779	013079	49.3	94.6	.50	.21	.98	.10	13.1	998.8	12.7	1027.8	982.7	8.7	.43	9.5	7.9	48
54650/1650	011479		64.5	152.9	.44	.22	1.29	.04	12.9	980.6	13.3	1004.5	935.6	.1	.19	.6	-.3	147
54651/1651	011079		57.5	105.8	.61	.31	1.76	.08	12.9	990.0	8.9	1009.5	975.7	5.3	.68	8.5	4.3	139
54652/1652	011279		61.2	127.2	.52	.24	1.21	.12	12.4	988.3	9.7	1011.8	963.2	1.7	.78	3.1	.6	115

NUMBER OF OBSERVATIONS = 5053. BUOY SENSOR PERFORMANCE - 97.32% POSITION FIX PERFORMANCE = 99.13%
F - SENSOR DATA INVALID BUOY 1607 IN COASTAL WATERS BUOY 1639 NOT YET ON GTS
NETWORK PERFORMANCE - 92.34%

Figure 7.--Operational summary - January 5, 1979 - March 5, 1979.

The comparisons of means and standard deviations of pressure and temperature from the drifting buoys with means and standard deviations of pressure and temperature for comparable locations from synoptic charts of pressure and temperature for the same dates confirmed the overall excellent performance of the drifting buoys.

As of November 6, 1980, the original 64-buoy network had logged in over a total of 18,000 buoy days of operation since the start of the Global Weather Experiment. Considering all failure modes (except four deployment failures), the average time to failure was 319 days. The average time to failure is defined as the total buoy network operating time divided by the number of failed buoys. The average age of failed buoys was 290 days. The average age of failed buoys is defined as the total of failed buoy operating times divided by the number of failed buoys. The cumulative failure distribution is shown in Figure 8.

5. CONCLUSION

The feasibility of economically and reliably deploying meteorological drifting buoys in the remote data-sparse areas of the world has been shown during FGGE. The performance of the U.S. drifting buoys during the experiment indicates that about 80 percent of the buoys can be expected to remain operational for at least one year.

These drifting buoy-derived data have also proved extremely valuable in overcoming weather forecasting problems arising from the deficiency of surface observations in the oceans of the Southern Hemisphere. The experiment has provided the operational experience and data network performance characteristics needed for the planning, design, and implementation of future drifting buoy monitoring systems.

An operational polar-orbiting satellite network, reliable data processing, and a data dissemination network have been established to provide a global environmental monitoring capability during the next several years. Planning is underway to continue this capability into the next decade.

It is expected that drifting buoy technology will play an increasingly important role in climate-related research programs during the next decade. Climatically important ocean processes are presently poorly understood, due mainly to the relative lack of long-term, synoptic time series data defining large-scale oceanic variability. Comprehensive data sets are needed for ocean climate diagnosis, for model development and validation, for process-oriented studies, and for investigations of ocean-atmospheric coupling.

Meteorological drifting buoys with increased measurement capabilities, in conjunction with other remote measurement systems, will play a key role in providing the needed data sets. The use of drifting buoy data for improved surface analysis in the Southern Hemisphere has been amply demonstrated during FGGE. Within the next several years, operational drifting buoys may become a major source of meteorological data for forecasting purposes along with other remote measurement systems.

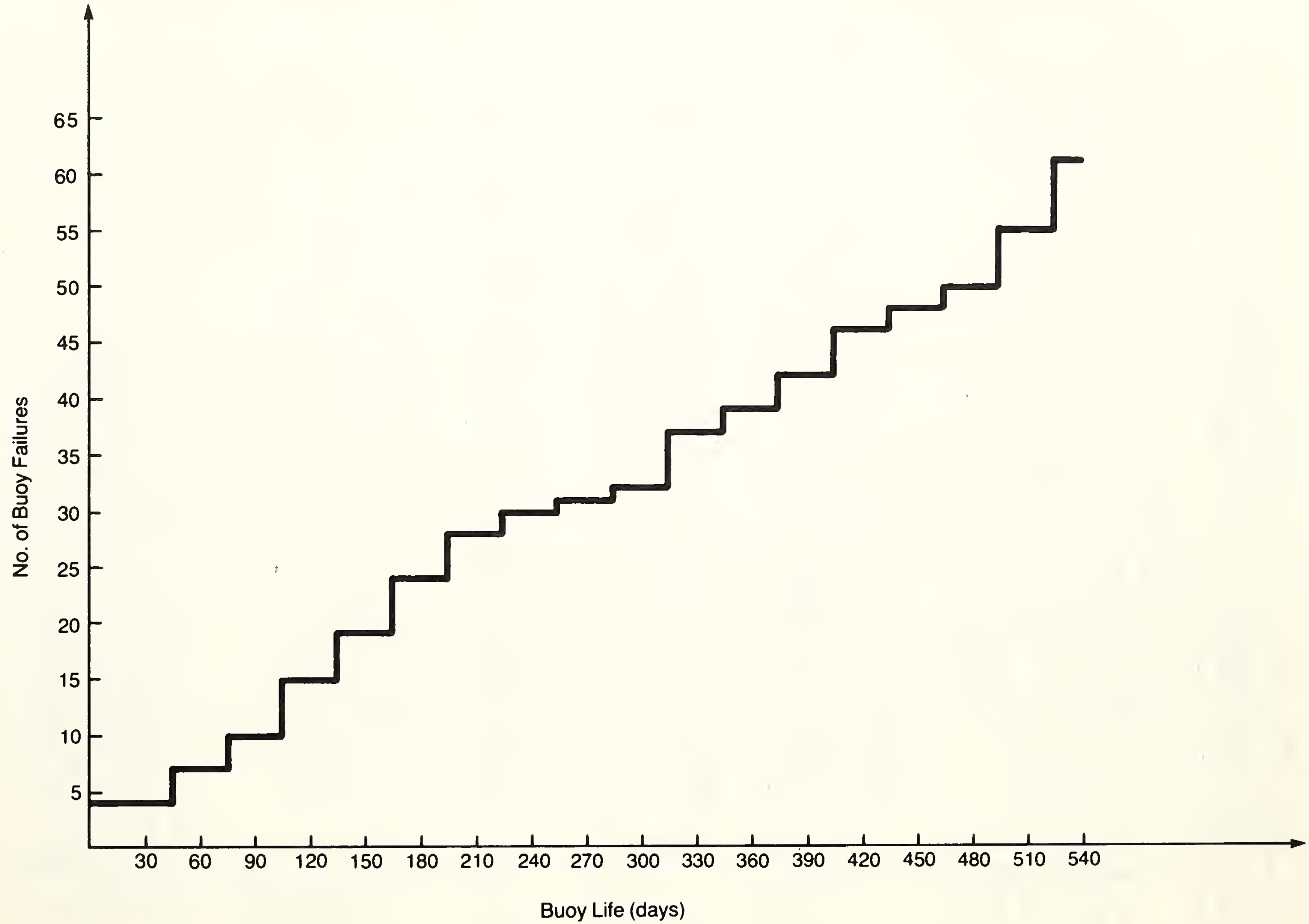


Figure 8.--Cumulative distribution of FGGE buoy failures.

CHAPTER 5

TROPICAL CONSTANT LEVEL BALLOONS

By
E. W. Lichfield (NCAR)

1. INTRODUCTION

The following is a brief report on the operational aspects of the Tropical Constant Level Balloon System (TCLBS) in the Global Weather Experiment. The data management, data processing, and use of the TCLBS data in the analyses are not included here.

2. PURPOSE OF THE TCLBS

The TCLBS was deployed for the two Intensive Observing Periods (IOP's) to fill a gap in the observations of the tropical wind field in the upper tropical troposphere. This gap, in a critical region of the atmosphere, arose because of the altitude limitations on airacraft dropwindsonde observations. The objective of the TCLBS was to deploy superpressure balloon systems into the upper tropical troposphere so that winds derived from satellite tracking of these systems might fill in this spatial gap in the tropical observing network.

3. TCLBS DESCRIPTION

The balloon platform was designed to float at a density altitude equivalent, in the tropics, to approximately 140 mb. Tracking and data collection was performed by Service ARGOS, Toulouse, France, using the ARGOS system on TIROS-N. During each observing period, approximately 80 balloons were planned to be launched from each of two launch sites, located at Canton Island in the Pacific (2.8°S, 171.5°W) and Ascension Island in the Atlantic (7.9°S, 14.4°W). A nominal 6-hour launch interval was planned with launches to begin about one week before each IOP and continue until all platforms were launched. The launch frequency could be modified if unfavorable weather occurred at the launch site or if it was expected that flow patterns at altitude would cause the balloons to stream into higher latitudes of either hemisphere.

Because the platforms drift with the surrounding wind field, and because the density surface on which they are constrained to move varies with time, latitude, and longitude, two consequences follow. First, air safety and political considerations necessitated the incorporation of two cut-down destruct systems that were intended to prevent the platforms from drifting northward into temperate latitudes or descending (in pressure altitude) into commercial airspace. Second, the general circulation of the upper tropical troposphere and the lower temperate stratospheres will disperse the balloons so that they may not remain in the tropics, nor can an even distribution in longitude be expected. These considerations make any evaluation of TCLBS performance difficult, because one cannot reasonably erect standards against which to measure performance.

4. RESULTS FOR IOP-1

Launches commenced at both sites on 6 January as scheduled. A total of 78 platforms were launched from Ascension Island over a 27-day period and

Figure 1.--Launching of a balloon from Canton Island

75 platforms were launched from Canton Island over a 29-day period. Figure 1 illustrates the launching of a balloon from Canton Island under high wind conditions using the mobile launcher. The U.S. FGGE Coordinating Center (US-FCC) instructed the Ascension launch site to slow down the launch rate to one per day during 18-20 January, because the flow patterns at flight altitude were carrying the platforms too far into the Southern Hemisphere. Heavy rainshowers at Canton Island resulted in the launch of only one platform on 16 January and none on 18 January. During the period 22-24 January, the US-FCC instructed the Canton Island site to slow down the launch rate, because the change in upper air flow patterns resulted in previously launched platforms moving back over the Canton area.

Figure 2 provides a graphical summary of the cumulative number of balloons launched and the number of operational balloons as a function of the day of the year, 1979. IOP-1 spanned day 15 (January 15) through day 52 (February 21); the maximum reached was 82, and the overall profile, compared to that desired, was too 'peaked'. The principal failure mode for balloon loss causing this feature has been determined to be excessive loss in regions of deep convection. The platforms cannot survive, either because they accumulate ice, or because strong vertical currents force the balloons below the pressure altitude cut-down limit. The geographical distribution of platforms in IOP-1 was about as anticipated, but the almost complete lack of trajectories over the Indian Ocean was quite striking.

5. PROBLEMS AND ADJUSTMENTS FOR IOP-2

The launch strategy for IOP-2 was modified to: (1) achieve a more even distribution of operational platforms vs. time; (2) maintain a maximum number of platforms up for as long a period as possible; and (3) improve the geographical distribution of platforms. The launch frequency was reduced to two per day (per site) with launching commencing about ten days before the beginning of the IOP. Further, a third launch site was added. Because of its crucial and logistically attractive location, Guam was also selected to launch platforms during IOP-2. The anticipated upper flow was expected to carry the balloons into the Indian Ocean/Indonesia area.

The portion of Figure 2 pertaining to IOP-2 shows that the altered launch strategy was successful, in that more platforms were operational for a longer interval of time than during IOP-1. The maximum reached was over 100, with 70-odd platforms still up at the end of the IOP. The geographical distribution was also improved, with most of the Guam platforms spending some time over the Indian Ocean.

6. OVERALL PERFORMANCE

Figure 3 illustrates the location of balloons at the time of their final transmission. The clustering of last locations gives insight to the cause of balloon termination. In IOP-1, there is a cluster of last locations near Canton Island where there were large convective storms during the same period (see Figure 4). Clusters of last locations also occur over Africa and South America, and again there were large storms present. Counting the number

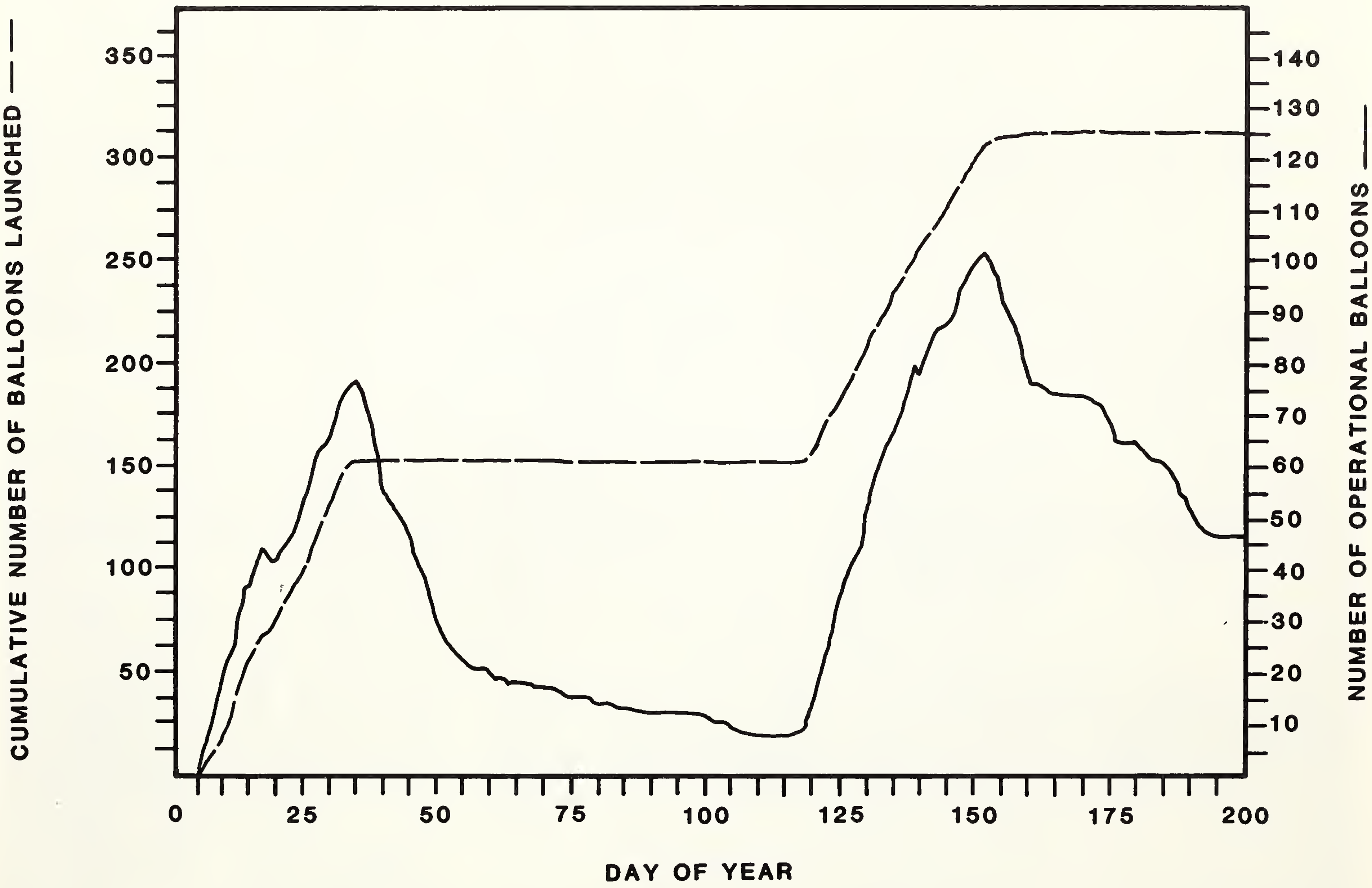


Figure 2.--All launch sites (Canton Island, Ascension Island, Guam).

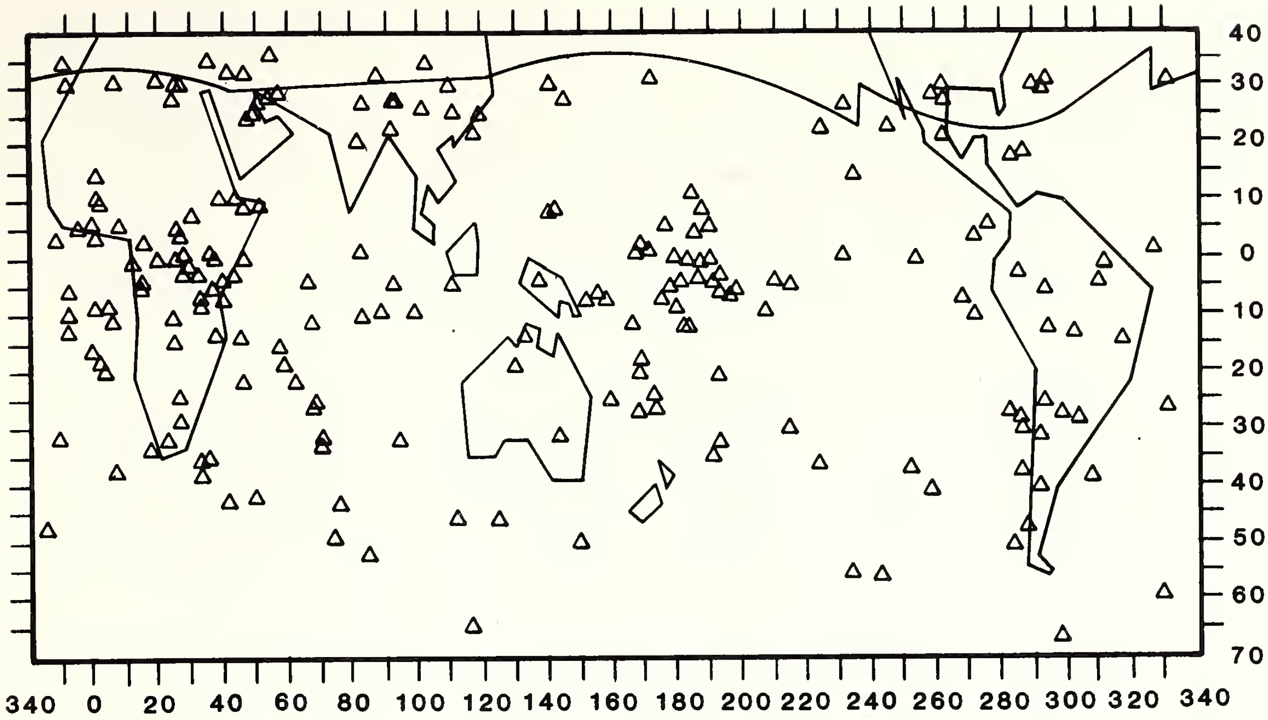


Figure 3.--Balloon locations at the time of final transmission.

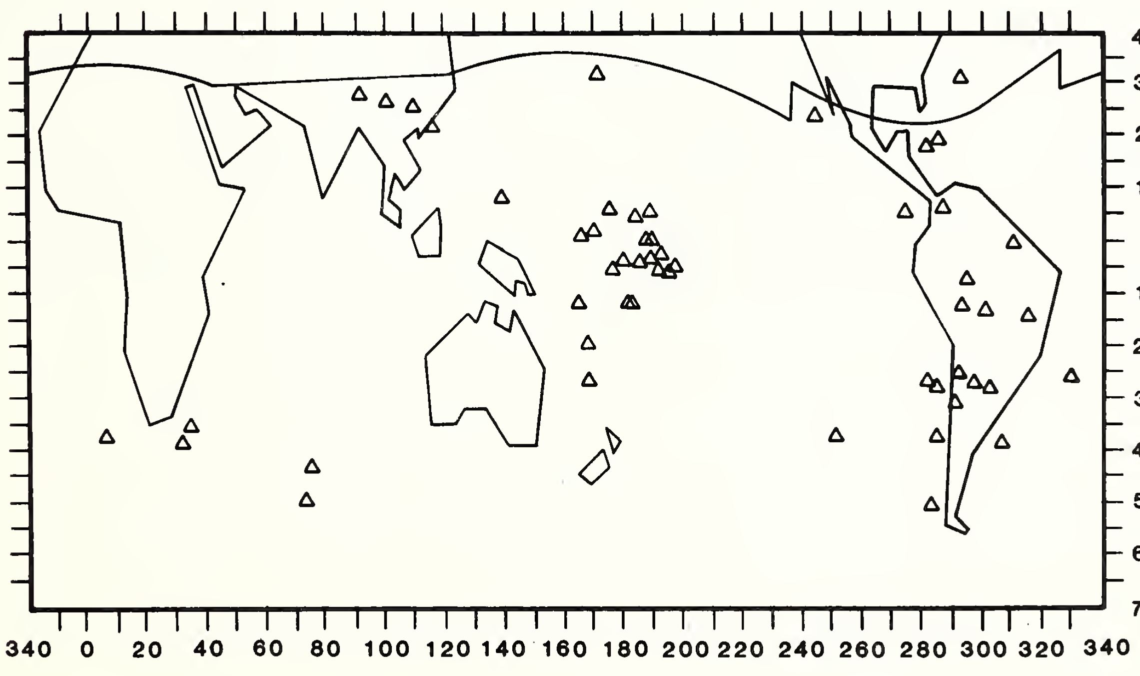


Figure 4.--Last location--Canton balloons SOP-I.

of last locations that occurred in regions of convective storms gives an estimate that more than 87 balloons were destroyed by convective storms. Counting the number of last locations that occurred near the magnetic cutdown lines gives an estimate that 58 balloons were terminated by the built-in magnetic cutdown system. Other balloons were lost to electronic failure, balloon failure, and pressure cutdown. The pressure cutdown system terminated the flight if the balloon descended into the commercial aircraft flight region. Since balloons fly at a constant density surface, they could descend below the set pressure cut level if the ambient air temperature was too warm. This would occur at high latitudes. Many balloons were undoubtedly cut down when they flew too far south.

The ARGOS system performed extremely well. On the average, data and locations were obtained for each balloon four times per day. This resulted in approximately 50,000 wind and temperature measurements for the complete balloon program. The balloon platforms transmitted 1 watt to the satellite. However, our tests have shown that 0.1 watt would have given location and data for 70 percent of the overpasses. Balloons were located that had gone to the surface and were hanging in trees.

Figure 5 shows the plotted data for 18 hours of balloon trajectory for all balloons flying on 16 June. The trajectories result in a presentation similar to a streamline analysis. Even with the limited data it is possible to construct a wind map that gives a picture of the tropical circulation that cannot be derived in any other way. Interesting features seen on the map are a blocking circulation in the Indian Ocean that is defined by a few balloons caught in this circulation, and slowly rotating counterclockwise. Balloons crossing Africa jam up against this circulation and eventually spill out across South Africa and then move rapidly across the South Indian Ocean, turning northward along the west coast of Australia. There are three waves in the equatorial Pacific. The most pronounced wave is over the north part of South America.

The Tropical Constant Level Balloon System produced a useful data set for the study of the wind circulation in the tropics. In addition, the experiment demonstrated that a balloon system is a practical and economically feasible means of collecting meteorological data in the tropics. The cost of each balloon flight was approximately $2,500. This resulted in 50,000 wind data points for a cost of approximately $16 per measurement.

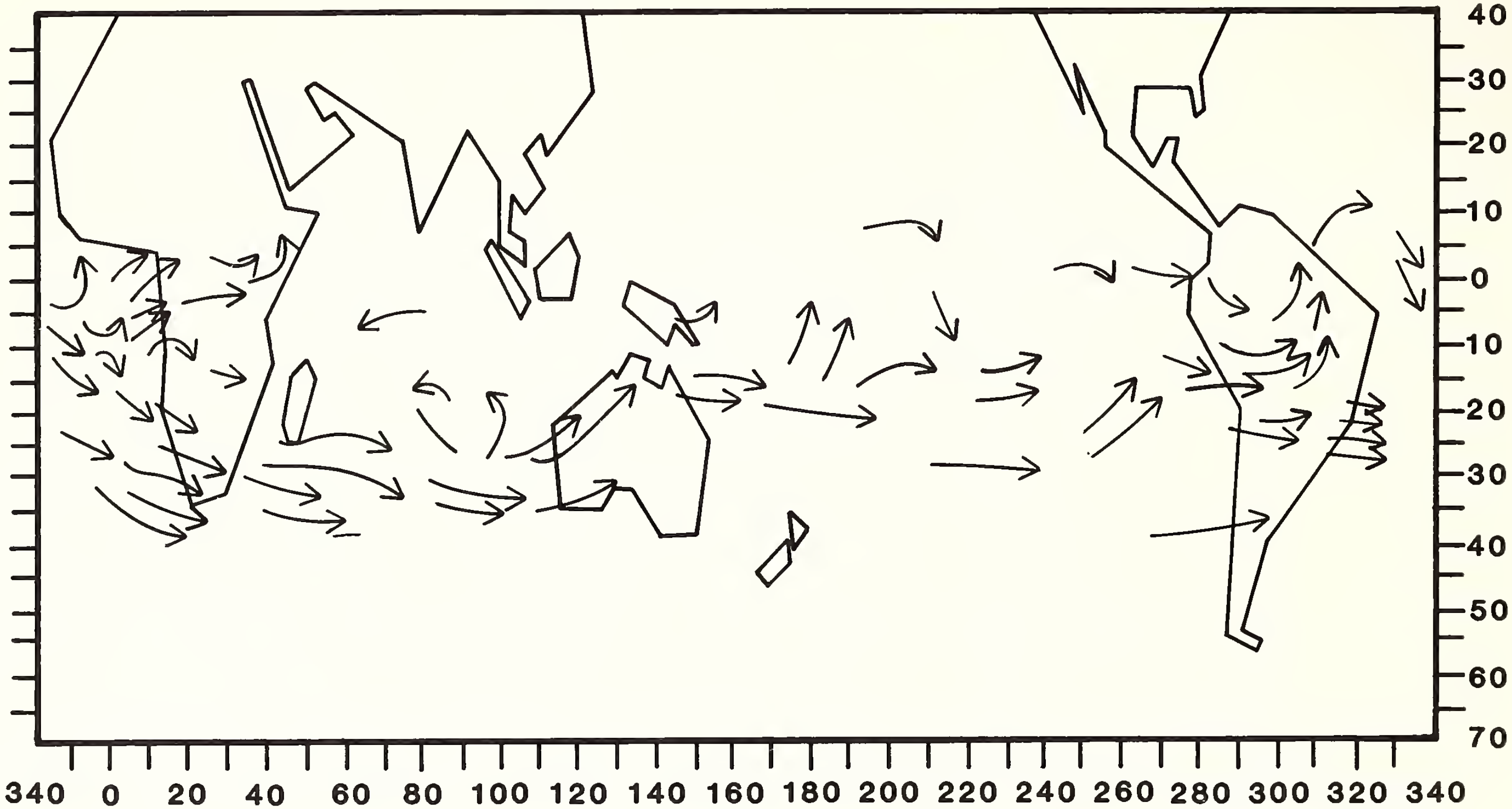


Figure 5.--Trajectory of all balloons flying on 16 June 1979.

CHAPTER 6

AIRCRAFT DROPWINDSONDE PROGRAM

By
O. Scribner (NOAA)
J. Smalley (NCAR)

1. INTRODUCTION

The purpose of dropwindsonde operations was to probe the tropical air mass. In the tropics the coupling between the pressure and temperature fields and the wind field is weak. Thus a separate measure of wind is needed there. It was the primary purpose of the dropwindsonde program to make soundings to obtain wind profiles. Pressure, temperature, and humidity data were collected at the same time but were of secondary importance. The flight tracks were preplanned. They were chosen to cover as much of the tropical ocean areas between 10°N and 10°S as possible, but to avoid large atmospheric disturbances or locales sounded by surface ships. Many operational considerations also influenced the final flight track configuration. These and many other details are covered in Chapter 7 "Dropwindsonde Operations".

2. HISTORICAL BACKGROUND

2.1 The Origins of Omega Windfinding

As best we can determine, John Beukers of Beukers Laboratories (1964) was the first person to propose that upper air windfinding might be done by a system which used retransmitted navigation aid signals to sense the winds aloft. Certainly, Beukers was the first to build a system (1967) that actually did the job, under a contract resulting from the strong support and amplification of Beuker's ideas by Chris Harmantas of the Weather Bureau. From 1968 to 1974, Beukers Laboratories designed and built increasingly more sophisticated NAVAID windfinding equipment. All of this early work was done with surface-based rawinsonde systems, first with LORAN-C, then the Omega, and later with Navy VLF Communications stations and the Soviet NAVAID system as signal sources. By the middle 70's, Beukers had even built equipment which could mix signals from different NAVAID systems as a source of positioning data for rawinsondes. Once proven for the case of land-based rawinsonde observations, it was a natural progression to think about using similar techniques for ship-based rawinsondes and dropwindsondes launched from aircraft. The NAVAID concept is particularly suited to these latter applications because, in contrast to the widely used radar or radio-direction finding (RDF) rawinsonde systems, no stable reference platform or mechanically complex precision tracking antenna are needed. Shipboard NAVAID equipment built by Beukers was used in the 1974 GARP Atlantic Tropical Experiment (GATE) and a shipboard system built by VAISALA and TRACOR was used in FGGE. Aircraft dropwindsonde equipment was used in both experiments.

The principles of windfinding with NAVAID signals have been discussed in the literature in great depth by Acheson (1970, 1978); Beukers (1967, 1972, 1975); Govind (1973); Olson (1977); Passi (1973); Poppe (1971, 1973, 1974, 1979); and others. Suffice to say here that systems designed to work with the worldwide

Omega NAVAID system use a sonde (balloon-borne or airdropped parachute supported) which receives the Omega signals (usually the 13.6 kHz transmissions) by means of a miniature Omega receiver in the sonde. The Omega signals then modulate a telemetry transmitter (usually in the 400-406 MHZ band) in the sonde, which then transmits to the receiving/processing equipment. Customarily, in most NAVAID windfinding systems, the sonde also contains pressure, temperature, and humidity sensors which generate additional signals which also modulate the telemetry carrier. The retransmitted Omega signals are subsequently processed by a computer which determines the changes in position of the sonde. The changes in position are a measure of wind velocity.

2.2 Evolution of the FGGE ODWS

The Omega Dropsonde Windfinding System (ODWS) is an improved version of similar equipment (described in several articles by Rossby, Govind, Cole, Pike, Norris, Saum and Lee, 1973) used successfully during the GARP Atlantic Tropical Experiment (GATE). The GATE system, and the dropwindsonde to work with it, were both developed, tested, and operated (in GATE) by a group of able scientists and engineers at the National Center for Atmospheric Research. It represented an important innovation in meteorological instrumentation - especially for the tropics where wind measurements are vital. For the first time one was able to obtain profiles of wind speed and direction, as well as temperature and humidity profiles, as a function of pressure, from the flight altitude of an aircraft to the sea surface. And the flexibility and range of aircraft operations made it possible to obtain upper air data over ocean areas not readily accessible by other means. But the GATE system required people with a high degree of skill and experience for successful operation. The system needed to be made simpler to operate and to be more compact and reliable, in order to make it suitable for use by trained weather observers and technicians operating from diverse types of aircraft at locations around the world.

Prior to FGGE entering the picture, NOAA's Environmental Research Laboratories (ERL) decided to begin work on a next generation of ODW systems which would take advantage of technological progress and the GATE experience. Dr. Stig Rossby (by then relocated to the Research Facilities Center of ERL at Miami), with considerable assistance from the NCAR team, began the development of a set of specifications for the new ODWS. When the Carrier Balloon System was eliminated from the FGGE plans, the U.S. GARP Committee agreed with the U.S. FGGE Office's recommendation to replace the carrier balloons with an aircraft dropwindsonde program. The FGGE effort was joined with the ERL initiative in the new ODWS program. TRACOR, in Austin, Texas, won the competition for the procurement of ten systems and was awarded the contract in June 1976. Dr. Rossby accepted technical responsibility for the joint ERL/FGGE effort and managed the test program using NOAA aircraft. The TRACOR "First Article" was conditionally accepted in early 1978, although the software continued to evolve for another year as further TRACOR equipment

and sonde tests and operations during the first FGGE Special Observing Period (SOP-I) uncovered areas of needed software improvement. The equipment proved to be significantly easier to operate and to be more reliable than the GATE version.

When the FGGE Project Office opted for the ERL dropwindsonde system as a major U.S. effort for FGGE, the Project Office entered into an agreement with NCAR for a companion effort to improve the sonde over that used in GATE. NCAR's Research Systems Facility undertook the work, with J. Smalley as team leader (described in an article by J. Smalley, 78/79). That development was completed in the early summer of 1977 with the delivery to NOAA from NCAR of a set of drawings and specifications for the improved dropwindsonde. VIZ Manufacturing Company, Philadelphia, was awarded the contract for 7,500 sondes in August 1977. Vernon Zurick of ERL was technical manager of the procurement, with Smalley and the NCAR team continuing as advisors. As intended, the new sondes were a major improvement, in reliability and performance, over the GATE sondes.

3. DESCRIPTION OF THE ODWS

The ODWS consists of permanently or semi-permanently installed equipment in the aircraft (the On-Board System) and dropwindsondes (sondes), one of which is expended for each sounding. The sondes, after ejection from the aircraft, telemeter signals back to the aircraft. The On-Board system receives the telemetered signals from the sondes; separates the Omega signals from the thermodynamic data; processes the Omega signals into wind speed and direction and the thermodynamic data into meteorological parameters of Pressure (P), Temperature (T) and Humidity (H); displays the processed data; and records semi-processed data on magnetic tape cassettes for more sophisticated post-processing. Following is a brief description of the Omega Dropsonde Windfinding System as used in FGGE.

3.1 Description of Aircraft On-Board System

Very briefly, the On-Board System consists of two antennae (one for local Omega and one for telemetry reception), Omega receivers, sonde receivers, cassette recorders, a computer and other data processing modules, a sonde preheat and baseline module, two solid-state teletypewriters, a chart recorder, a paper tape reader and a sonde launch tube. Figure 1 is a schematic block diagram of the equipment.

Besides power and crew intercom, the system requires input concerning aircraft navigation. There are several selectable modes of this input, three of which were used by various FGGE aircraft:

o The best mode, when the aircraft is equipped with an Inertial Navigation System (INS), is to obtain aircraft heading, ground speed, and flight level winds from the INS.

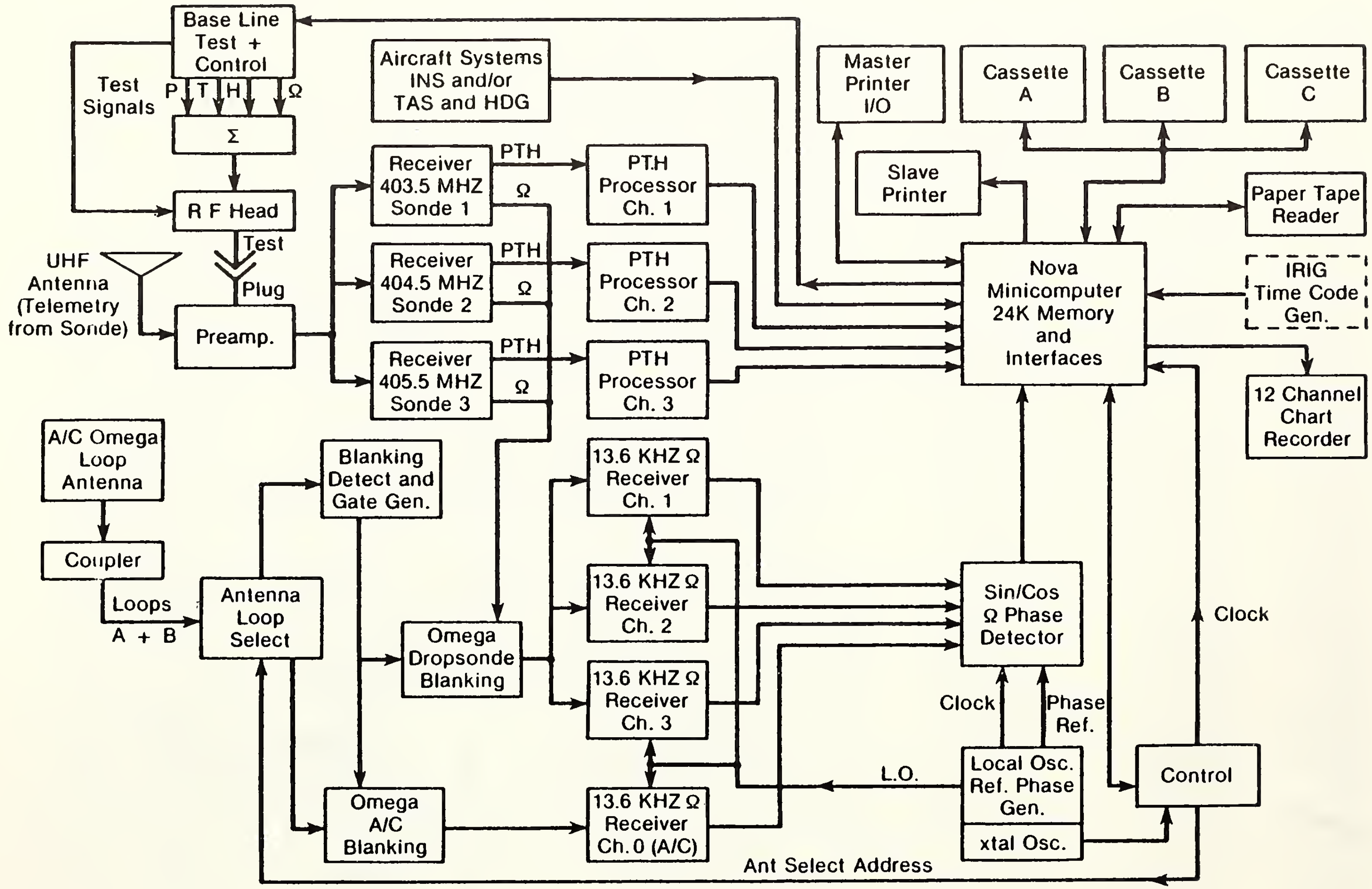


Figure 1.--Simplified block diagram of Omega Dropwindsonde Windfinding System.

o Lacking INS, direct feed of aircraft magnetic heading and true air speed from the air data system of the aircraft is normally used.

o As a fallback, true air speed and magnetic heading may be introduced manually through the keyboard of the master printer.

In the latter two modes, aircraft flight level winds, ground speed, and position are determined by the ODWS computer by combining the aircraft navigation inputs with the aircraft-received Omega data. Besides the flight level meteorological information, these inputs are used by the system to perform so-called "rate aiding" corrections[1].

Referring to the schematic, one sees that there are three sonde channels, operating at fixed frequencies of 403.5, 404.5, and 405.5 MHZ. Each channel has its own telemetry receiver, Omega receiver/preprocessor, and PTH preprocessor. There is an additional Omega receiver/preprocessor for the aircraft-received Omega signals. There are also three magnetic tape cassette decks, any one of which can be connected to any sonde channel, or to the aircraft data channel, by command via the keyboard. It is possible for the system to handle all three sonde channels simultaneously, but it is not possible, for obvious reasons, to handle two sondes of the same frequency at one time. Thus, with proper rotation of sonde frequencies (sondes are not tunable, but each sonde is manufactured with one of the same three fixed-channel frequencies), it is possible to have up to three sondes in the air at the same time. During FGGE, two sondes in the air at once was commonplace, though working all three channels at once was very rare.

For each observation, baseline data, flight level winds, and aircraft navigation are recorded on the printers and on the magnetic tape. Also appearing in both recording modes are certain data entered manually by the operator through the master printer keyboard: sonde identification, date, etc., so that the observation may be properly identified. The paper tape reader is used to introduce into the system the calibration data for each sonde (tapes for the purpose are packed with each sonde) and for some maintenance diagnostic programs. The main program load is done from a cassette magnetic tape program fed through one of the cassette decks.

The sounding data appearing on the printers and recorded on the cassette tapes are not the same. The printed data have been fully processed into meteorological parameters by the ODWS computer; that is, the data are "real time". The data recorded on the cassettes, on the other hand, are "raw" and require subsequent post-processing in non-real-time. The cassette data, besides the same header information and time indices as the printed

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[1]The Omega system transmissions are sent in time sequence. Each station transmits each ten seconds for a period of 0.9 to 1.2 seconds. Successive 10-second data points are used to detect movement of the sonde, with the assumption that the velocity of the aircraft remains constant between data points. If the aircraft accelerates by changing speed or direction, the assumption is not valid and the computer must make corrections to the Omega phase data.

information, consist of the raw frequencies representing temperature, pressure, and humidity, along with the semi-processed Omega phase numbers for each Omega station. For research efforts not requiring real-time weather analysis, the cassette data may be processed on a large-scale computer where much more sophisticated techniques are possible than in the ODWS mini-computer. Also, post-processing allows editing, smoothing, and interpolation to be done with computer-human dialogue -- preliminary steps that can rescue otherwise bad data. The large computer, with its greater computational and storage capabilities, is able to produce more reliable and accurate results in cases when the sonde Omega data are weak or erratic. In cases where good Omega signals and good geometry exist, our experience has been that the real-time data are virtually identical to the post-processed data.

The strip-chart recorder is provided as an aid to operators and maintenance technicians to assess the performance of the system; it is not an essential component so far as normal data collection is concerned. The operator can select from a wide range of raw and processed data for presentation on the strip-chart. Up to eight parameters may be recorded simultaneously.

After the system has had power applied and the computer program[2] is in memory, an initialization procedure is started. This includes synchronization with the Omega signals, choice of the navigation mode to be used, specifying the source of true air speed and heading information, entry of aircraft position, date and time, logging of aircraft (as opposed to sonde) data, Omega station pair selection and logging of self-test data. Recorders are selected for each sonde frequency, and the types of data to be plotted on the chart are selected. All of these data are supplied in response to queries typed out on the master teletype. At times the keyboard is locked out while the system is performing certain functions. If an improper answer is given to a query, the system will usually recognize the fact and ask again.

Each of the three sonde frequency channels can be checked with an elaborate computer-controlled test of frequency respsonse, FM, P, T, H, and Omega signal processing. A test of any one of the three channels is run whenever proper operation is questioned. Because there are three frequency channels available, any nonfunctioning channel can be avoided. The quality of the received Omega signals can be assessed at any time. The computer prints a table of range and bearing to each transmitter and quality of signal for all eight stations.

The above items are done on an as-needed basis. There is a pattern of steps followed with each sonde. Each sonde is warmed up in the preheat chamber. There is no computer control on the length of time for preheat, but 15-30 minutes is desirable. During this time, the sonde battery condition and transmitter operation can be checked manually. Also, the sonde calibration tapes are stored in the computer. Prior to launch each sonde is "baselined". Here outputs of P, T, and H are compared with reference values. The

[2] Normally the computer program is already in the memory as it is nonvolatile.

reference T and H signals are generated by precision resistors which temporarily replace the sensors. The pressure sensors are checked against a reference pressure transducer built into the system. Signal strength, battery voltage, treansmitter output, and correct Omega reception are tested. The particular frequency channel is also tested for interfering signals. After baselining is successfully completed, the sensor assembly is installed, the sonde is turned on, inserted into the launch tube, and launched. There are multiple controls to ensure that each step is followed and in the proper sequence.

During the sonde descent, real-time data are printed on both the master and slave printer. After splash down or any signal fade, a message is displayed indicating signal loss.

3.2 The Dropwindsonde (or Sonde)

The FGGE dropwindsonde is designed to sense pressure, temperature, humidity, wind speed, and wind direction profiles, as a function of time, in the atmosphere between the launch altitude of the aircraft and the sea-surface. Pressure is sensed by an aneroid cell which drives a variable capacitor. Temperature is sensed by a bead thermistor. Humidity is sensed by a carbon hygristor similar to that used in standard U.S. radiosondes but modified for faster response (approximately 1/4 the mass of the standard hygristor). The designed pressure accuracy is ± 2 millibars; the designed temperature accuracies are ± 0.5°C for temperature between 0°C and +40°C, and ± 1°C between 0°C and -55°C; the designed humidity accuracies are ± 5% above 0°C, ± 8% between 0°C and -20°C, and ± 13% between -20°C and -40°C. Humidity is not evaluated at temperatures below -40°C. The pressure cell, hygristor, and thermistor control oscillators, the output of which modulate the sonde telemetry carrier. Winds are obtained by the retransmission of Omega navigation signals. The sonde receives the 13.6 kHz Omega signals and retransmits them to the aircraft by also modulating the telemetry carrier. Wind accuracies derived from the Omega signals are highly dependent upon the quality (signal to noise) of the Omega signal, the position of the sonde in space relative to the position of the Omega transmitters whose signals are used, and the presence or absence of propagation anomalies. Over a large part of the world, winds accurate to better than ± 2 mps are usually obtainable when integration periods of four minutes (100 millibars) are used.

The FGGE Dropwindsonde is a cylinder 3-1/2 inches in diameter and 18 inches in length (Figure 2). The outer case is rigid phenolic to withstand handling, launch forces, and aerodynamic forces. At the instant of ejection from the aircraft, a loose fitting cover[3] holding a small drogue chute in place is blown away and the drogue is immediately deployed by the

[3]The drogue cover comes with a ribbon attached but the ribbon was usually removed as it sometimes significantly reduces the speed of motion of the sonde through the launch tube.

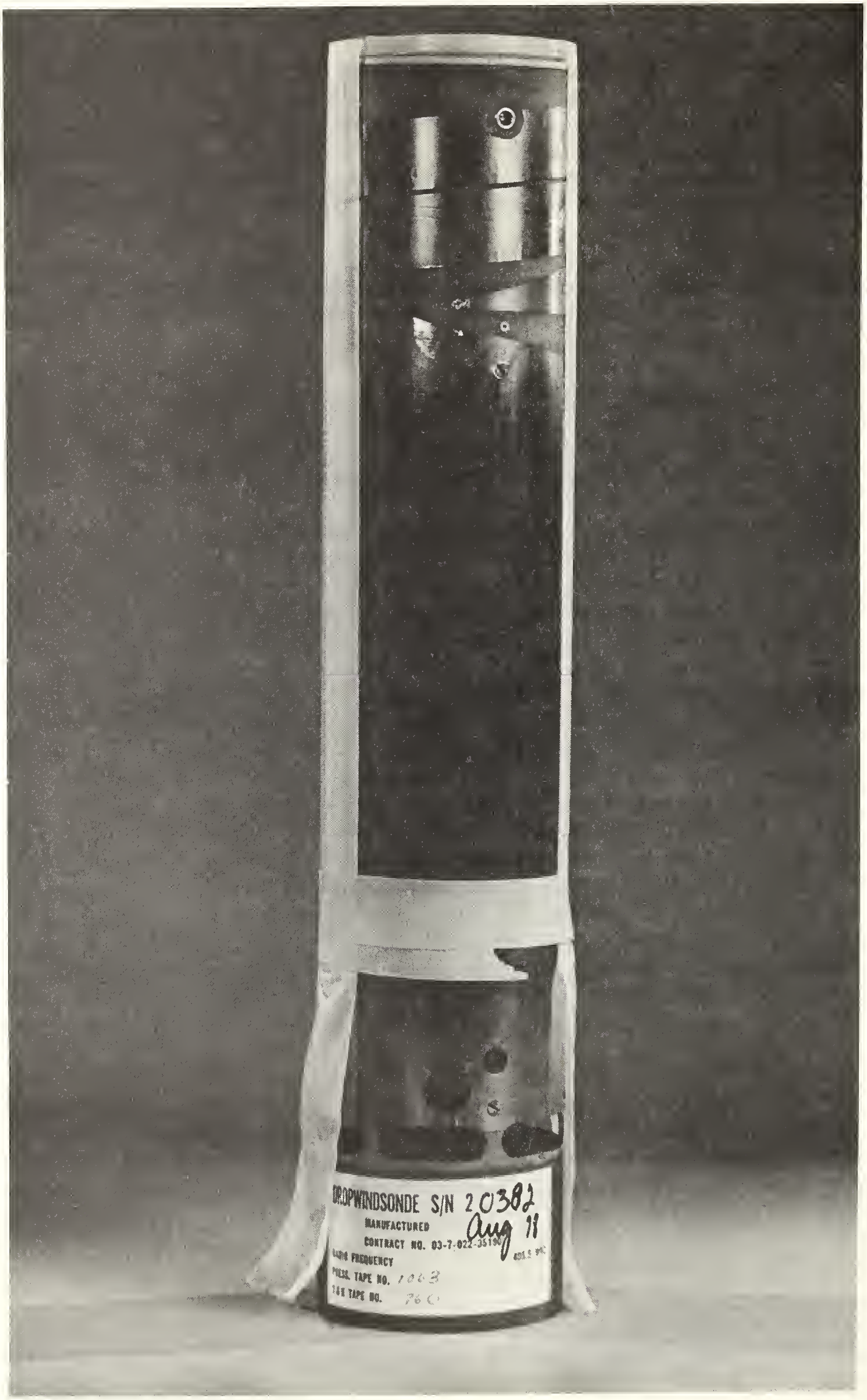

Figure 2.--Dropwindsonde

airstream. A pin is pulled when the drogue deploys, starting a timer. After seven seconds, the sonde has lost all forward motion imparted by the launching aircraft and is falling vertically.

After the seven seconds, another spring-loaded pin retracts and the chute cover, with timer, is free to come out of the end of the sonde. The drogue pulls out this cover, which releases the main chute. Suspended by the main chute, the sonde falls at a speed of 25 to 30 mb per minute. This corresponds to about 4m per second at sea level. Both chutes are cross-type, the drogue having lay-flat dimension of one foot and the main of 5-1/4 feet. The cross design has a major advantage of usually having little pendulum-type oscillation. The main chute is attached to the sonde with a 20-foot nylon riser line. The Omega receiving antenna is coiled around and deployed with the riser. The drogue chute is attached to the chute cover through a swivel since the drogue tends to spin rapidly. Spinning without the swivel would twist the chute shroud lines, reducing the size of the canopy, thus reducing the drogue effect. Should this happen, the sonde will fall in a flat spin, considerably increasing the chance of tangling the main chute.

At the front of the sonde, the thermistor and carbon hygristor are exposed to the air stream. They are in a duct designed to shield against direct solar radiation, to maximize air exposure, and minimize lags due to adjacent thermal masses. The hygristor is inside a shield to protect it from rain drops and indirect solar radiation (Figure 3). The aneroid pressure cell and its capacitive transducer are inside the sonde. All three sensors control individual oscillators. These outputs and the received Omega are frequency multiplexed and transmitted to the launching aircraft at 403.5, 404.5, or 405.5 MHz. The modulating frequency ranges used are:

Pressure :	1 kHz to 2.6 kHz
Temperature:	12 Hz to 650 Hz impressed on a 35 kHz subcarrier
Humidity :	25 Hz to 150 Hz
Omega :	13.6 kHz

The transmitting antenna is designed as a wrap-around on the outer case. The battery is made up of alkaline cells with a transmit lifetime of about 90 minutes. Power output is about one watt. Sonde weight, complete, is about 3-1/2 pounds.

During manufacture, the temperature and humidity oscillators are calibrated for output frequency as a function of input resistance. The pressure cell and its oscillator are calibrated for output frequency as a function of input pressure. All calibrations are punched on paper tape and the tapes are packed with the sonde. All thermistors used are specified to have a common calibration curve. All hygristors used have a calibration curve of the same shape, but the reference resistance, at 33 percent relative humidity, is individually measured and recorded for each lot. The thermistor and hygristor are supplied as an assembled unit (Figure 4), which is inserted into the sonde just prior to launch.

In a relatively inexpensive sonde, baselining, or pre-drop calibration check, of the sensor channels appears to be necessary. The FGGE sonde

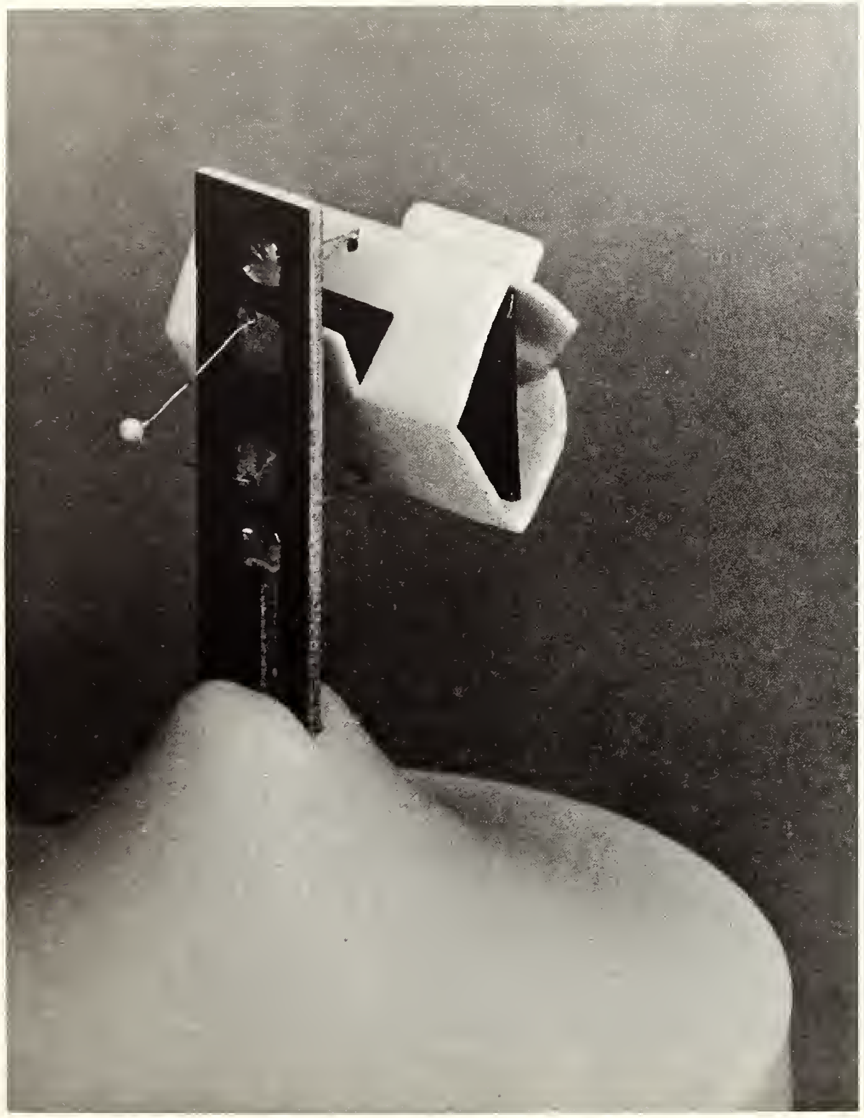

Figure 3.--Dropwindsonde thermistor and hygristor inside shield.

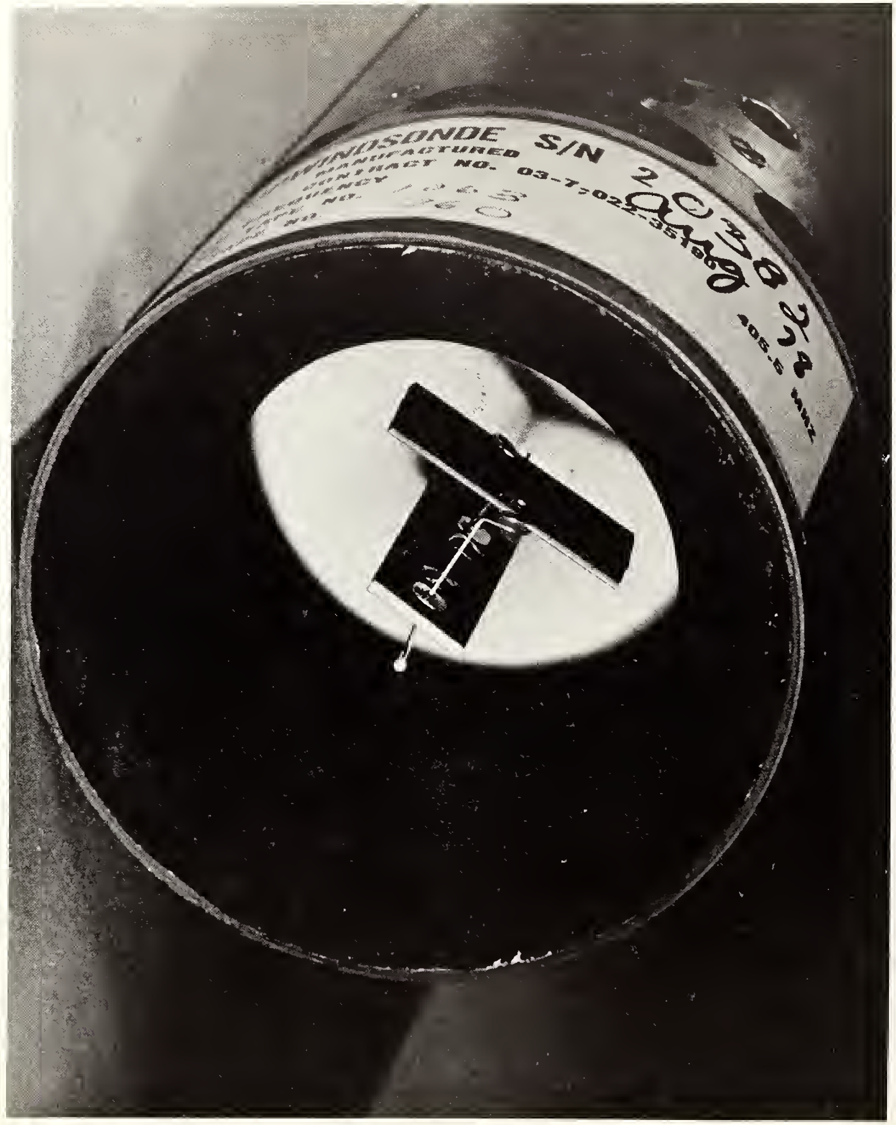

Figure 4.--Thermistor and hygristor with shield removed.

was no exception. After pre-heat, baselining was accomplished as previously outlined in Section 3.1 of this chapter. Pass limits were within:

± 2 degrees for temperature
± 10 percent for relative humidity
± 10 mb for pressure

From the baseline data, the computer automatically provided an offset correction from the factory calibration. But the above limits for that correction were established as being those within which the designed accuracies could be retained with only an unsophisticated offset to correct for small changes from the factory calibration. In FGGE, the operator had the option to override the "fail message" from the computer, as these thermodynamic parameters were of secondary importance.

4. SUPPORT ACTIVITY

4.1 Aircraft Installations

The FGGE dropwindsonde missions were flown by both NOAA and USAF aircraft. Two NOAA P-3s and one NOAA C-130 were permanently equipped with ODW systems prior to FGGE and will continue to employ them in research projects for the indefinite future. It was a different story for the Air Force planes. Those installations were temporary for the project and would be removed between the two Special Observing Periods, reinstalled, and permanently removed after SOP-II. This dictated that the ODWS console, sonde storage racks, pre-heat chamber, work table, operator chairs, and slave printer be placed on a pallet which could be readily installed and removed. The antenna, cabling to aircraft systems, and, in some cases, the launch tube had to be engineered for ready removal. There were two USAF installation programs: one for WC-135 aircraft and one for C-141s. Both programs were managed by Kenneth Foulke of the U.S. FGGE Project Office (NOAA). Of the two, the WC-135 program was the less difficult. The WC-135s already had launch tubes, and since their usual missions required considerable electronic equipment in the cabin, the aircraft interfaces were straightforward. Three WC-135s were equipped for a total cost of about $70,000 of FGGE funds, since Foulke could arrange for much of the work to be done at the home base of the aircraft by USAF technicians at little direct cost to the program.

The C-141 program was far more expensive, being accomplished entirely by a USAF contract to Lockheed, under the cognizance of the USAF depot at Warner Robins AFB. The C-141 is a cargo carrier, which meant that connection to aircraft systems was more complex, since there were no access points in the cabin. Special launch tubes were constructed integral with replaceable side escape hatches well aft in the aircraft. These reconfigured hatches replaced the standard hatch doors during times the ODWS was in use. Specially designed, readily removed tripod supports for the parts of the launcher extending into the cabin were fabricated. Expensive tests had to be run to ensure that the launcher location would eject sondes properly and that ejected sondes would not hit the aircraft. Altogether, the direct cost of designing, installing, testing, and removal of the ODWS on six C-141 aircraft approached a half million dollars.

An interesting feature of the C-141 installations, applicable only to the four aircraft which would operate in the Pacific, was the removal of all national and organization markings from the aircraft, excepting only the identifying "tail numbers". This was a stipulation of the Mexican Government in order that the aircraft could operate to and from Acapulco. In place of the USAF markings and American flag, a WMO insignia was placed on each side of the tail of each of the FGGE Pacific aircraft.

4.2 Training

The ODWS operators for the Research Systems Facility of ERL, which operates the NOAA aircraft, were trained on-the-job by Dr. Rossby who, as technical manager and test director for the on-board ODW systems, had become thoroughly familiar with running the equipment. That task was made easier, because the RFC engineers and technicians were already accustomed to operating complex computer-dependent scientific equipment on the NOAA airplanes. A much more lengthy and formal training program was needed for the weather observers who would operate the ODWS on the Air Force aircraft.

Lt. Col. Rich Chapple and Master Sergeant Lee Weiher of the USAF Air Weather Service (AWS) conducted a recruiting and screening program of volunteer AWS weather observers to select the ODWS operators for the participating USAF aircraft. They selected four senior non-commissioned officers (one of whom was Weiher), and twenty-two airmen to undergo special training for the FGGE ODWS project. Each of the senior NCO's would later be an ODWS operator supervisor at a FGGE operating location, and the other twenty-two became the equipment operators for the WC-135 and C-141 aircraft.

Following flight qualification by the Air Force, the trainees were divided into four classes. Each class attended two weeks of "ground school" at the TRACOR factory conducted by TRACOR engineers and software specialists. Half of that time was spent in "hands-on" practice with two ODW systems which had been set up as simulated flight trainers; the other half in classroom work to provide an understanding of sonde preparation, of Omega windfinding theory, of the reasons for the many actions required of an operator to obtain a valid sounding, and of the special operator actions needed in FGGE.

Each class then went to Miami for a week of basic flight training in NOAA aircraft, under Dr. Rossby's direction. During that week, each operator flew four practice missions and made a number of soundings using production sondes. Purposely, both phases of the training was arduous, both mentally and physically, in order to ensure competent operators for the project. All but one trainee finished as qualified ODWS operators - a tribute to the AWS selection process. Shortly before deployment of crews and aircraft for the FGGE SOP-I, each operator was afforded one more flight for proficiency and refresher training. Upon deployment, en route to the operating locations, still more sondes were dropped as a crew coordination exercise.

The costly and demanding training program, and the large number of expensive sondes expended before a single FGGE observation was made, paid off handsomely. A new system, with operators who until selection were not at all familiar with running systems of this complexity, combined to produce good results from the first day on station.

4.3 Logistics Support

Good equipment properly installed, proficient operators, an adequate supply of sondes, and carefully planned missions served to get things started on the right foot, but more was needed to minimize subsequent shut downs. The best of aircraft and electronics equipment will malfunction from time to time. Provisions for restoration to service had to be made if the FGGE aircraft dropwindsonde program was to succeed.

The NOAA and Air Force aircraft units were both accustomed to operating away from home base, and had already-developed maintenance support arrangements. While some missions were lost due to aircraft outages, the only devastating impact on FGGE from that source occurred at Ascension Island during the first SOP. Smalley, in his report on the Atlantic operations, discusses that issue in Part 2, Chapter 7, of this report. Suffice to say here that maintenance problems with the WC-135 aircraft at Ascension resulted in less than half of the scheduled missions being flown over the Atlantic in SOP-I. As a result of that disappointing performance, the WC-135s were not used in SOP-II. Instead, two additional C-141s were outfitted with the ODWS between the two SOPs and were deployed to Ascension for SOP-II, with excellent results.

The logistic support for the ODW systems themselves had to be developed specifically for FGGE. Long before deployment, three types of spare parts kits were procured. With the help of the TRACOR engineers, maintenance parts were identified, based on statistical probability of failure, in three categories:

o Each ODWS had its own set of running spares of small items, kept with the equipment.

o A second set of more expensive spares, containing parts with a lower probability of failure, was provided for each operating location, to support a number of ODW systems.

o A third set of vital but unlikely-to-fail parts was procured and kept at one central location along with a complete back-up system.

The spare parts are of little value without expert repairmen to use them. The NOAA RFC has a few individuals with the necessary background and experience to enable them to become ODWS repairmen in a relatively short time. Also, since RFC plans to retain the systems indefinitely, it was worthwhile to expend the required time and effort to develop the new skills. Thus, the ODW systems on NOAA aircraft were maintainable within NOAA resources.

For the Air Force aircraft, NOAA contracted with TRACOR to place a qualified maintenance technician at each operating location during each of the two SOPs. Excellent service was obtained from these individuals. ODWS outages were a serious problem only during the second SOP in the Pacific, where a rash of failures of the NOVA computer core memory boards exhausted the prepositioned spares and threatened for a while to collapse operations there. It is suspected, though not proven, that lack of air-conditioned storage between SOPs, during the time that the equipment was not in the C-141 aircraft, contribiuted to premature failures of the NOVA core memory boards. NOAA was fortunate to locate a source from which reconditioned NOVA core memories could be bought on short notice (lead time quoted by the manufacturer and its distributors for new boards or repair of old ones ruled out those sources). Emergency purchase of the reconditioned boards and employment of extraordinary means for their rapid shipment rescued the Pacific systems, but not before several missions were lost.

5. SOME COMMENTS AND CONCLUSIONS

Despite the computer problems in the Pacific during the second SOP, and the C-135 maintenance problems during the first SOP, the FGGE Dropwindsonde Program, overall, was a success. It made a critically important contribution to the FGGE data set; for without it, large areas of the tropical oceans would have been void of the vertical wind profiles considered essential by the scientists who planned the experiment. The success was partly due to careful planning of flight operations, installation, logistic support, and operator training, and of course to the timely development and procurement of the ODWS onboard system and sondes. But the critical factor was competent and dedicated people in NOAA, NCAR, the Air Force, and perhaps most importantly, in the three business firms which produced the system, built the sondes, and converted the C-141 cargo carrier into a scientific research platform.

CHAPTER 7

DROPWINDSONDE OPERATIONS

PART I: THE PACIFIC

By
Edward Tiernan
(U.S. FGGE Project Office)

1. INTRODUCTION

Prior to the Global Weather Experiment, San Cristobal, in the Galapagos Islands, was the only operational upper air station in the 8 million miles of open ocean area between the west coast of South America and the International Date Line and between the tenth degrees of latitude north and south. Its data were occasionally supplemented by intermittent upper air observations made by the University of Hawaii on Fanning Island at 160 degrees west. A total data void existed between these two island stations.

Starting in December 1978, two upper air observations a day from tiny Penryhn Island became available as a result of a special U.S. effort for the Global Weather Experiment. A month later, two observations per day from Canton Island were added, and the Fanning Island schedule was also increased to two observations daily. Early in January, ships equipped with special upper air systems arrived in the area and commenced upper air observations at local noon and midnight. By mid-January huge Air Force C-141 aircraft were flying daily sorties over the area, dropping windfinding sondes every 350 kilometers along specially designed tracks. A major effort was underway. The winds aloft over the tropical Eastern Pacific were being measured as they never had been before. Similar efforts were underway in the Atlantic and the Indian Oceans. It was the beginning of the first Special Observing Period (SOP) for the Global Weather Experiment.

It is not likely that such a massive effort will be mounted again soon. However, the experience gained in the planning and execution of such a large-scale experiment could be useful to others in the future. This chapter presents a brief discussion of the factors taken into consideration in the planning and implementation of the operational aspects of the Pacific Dropwindsonde Program as well as the major problems encountered in its execution.

2. OPERATING LOCATIONS, FLIGHT TRACKS, AND AIRCRAFT UTILIZATION

Four Air Force C-141 aircraft from the Military Airlift Command were available for the Pacific area. To obtain as many spatially independent dropwindsonde observations as possible, the strategy for employment of the aircraft was quite simply to fly them as high and as far as possible in the zone between 10 degrees north and 10 degrees south latitude. To accomplish this, two suitable operating locations in, or as close as possible to, the zone had to be found. When all the requirements for the operating locations such as location, runway length, maintenance facilities, and logistic support capabilities were considered, it was determined that Hickam AFB, Hawaii, and Acapulco International Airport, Mexico, would be the best choices. A third possibility was Howard AFB, Panama. However, C-141s operating from Howard AFB could not reach Hawaii nor could nonstop round-robin flights from either Hickam or Howard (round-robins) extend far enough eastward or westward to provide the required coverage of the central portion of the Eastern Pacific. Plans were therefore developed for the use of Hickam AFB and Acapulco International, with Howard AFB to be used in the event of problems in obtaining operating rights at Acapulco.

Figure 1 in Part 4 of this Chapter illustrates the primary tracks planned from Hickam and Acapulco (P10, P20, and P30). If possible, each of the three tracks would be daily, with one of the four aircraft held in reserve. The actual tracks flown on any given day were selected based upon the location of the Intertropical Convergence Zone (or any organized deep convection) and the location of upper air observing ships on that day. A fundamental principle of the drop strategy was to avoid deep convection where the descending sonde would be subject to small-scale air currents in the convective cells rather than the large-scale flow desired. Drops in the vicinity of upper air observing ships were to be avoided to maximize the unique spatial contribution of each observation.

The initial deployment plan was to place two aircraft at each operating location. The four aircraft would then be rotated through the system of tracks. However, because of limited parking space for aircraft at Acapulco, it was not feasible to have three on the ground there on a routine basis. Hence, the reserve aircraft would have to be kept at Hickam AFB. The first shuttle (P-20) was to be flown westward from Acapulco and the second eastward from Hickam; this rotation would continue throughout the operation. On alternate days there would be one and two aircraft at Acapulco with three and two at Hickam. Considering the relative capabilities for maintenance and logistic support at Hickam AFB and Acapulco, the reserve aircraft should have been stationed at Acapulco, which had the lesser support capability. However, with an in-bound shuttle to Acapulco every other day, which could carry spare parts for either the aircraft or observing system, it was felt that Acapulco could be adequately supported.

2.1 The Move to Panama

Plans for the eastern Pacific coverage were essentially complete by mid-June 1978. Clearance from the Government of Mexico (GOM) for the use of Acapulco was all that was still required. It was not until November 20, 1978, that the U.S. was informed that the GOM wanted the operations from Acapulco to be conducted under a formal agreement between the WMO and the GOM. Even at this late date, we remained optimistic that the first SOP would start on time; we seriously underestimated the task. Intensive efforts were made to conclude the agreement on time. However, the U.S. Embassy in Mexico City was notified by the GOM on January 19, 1979 (four days after the scheduled beginning of SOP-1) that "Mexico regrets that it will be unable to participate in the first SOP". The contingency plan for operation from Howard AFB in the Panama Canal Zone had to be implemented.

2.2 SOP-1

While efforts were going on in Mexico City to conclude an agreement for the use of Acapulco, personnel and aircraft for the eastern Pacific program assembled at the predeployment staging base at Norton AFB, California, on January 11th and 12th. On January 13th, when the four aircraft were scheduled to deploy, and with the situation concerning Acapulco still unresolved, only the two aircraft bound for Hickam AFB departed on schedule. The other two C-141s, flight crews, ground support personnel, and observing system operators remained at Norton AFB awaiting clearance to proceed to Acapulco.

The first scheduled sortie for SOP-1 was to be the Acapulco to Hickam shuttle on January 15. However, with no clearance from Mexico, the planned shuttle could not be flown. In its place two round-robin sorties, a P-30 to the west and its mirror image to the east (called a P-30 FLOP), were flown from Hawaii. On January 17, 18, and 20, round-robins were flown from Norton AFB southward to 8°N latitude. On January 21, with the situation in Mexico settled at least for SOP-1, one aircraft was deployed to Panama to fly one round-robin sortie per day from there and a third was sent to Hawaii to provide a reserve aircraft there.

The first round-robin sortie from Panama westward to 113°W longitude was flown January 23. The two round-robins were flown from Hawaii, providing coverage from the date-line eastward to 130°W longitude. This was the mode of operation for the remainder of SOP-1. The Hickam-Acapulco shuttle had to be cancelled for the duration of SOP-1 and the area between 113°W and 130°W could not be covered. Figures 2 and 3 in Part 4 of this chapter illustrate the tracks actually flown in the Pacific during SOP-1.

The final day of SOP-1 operations for the entire dropwindsonde program was originally scheduled to be February 13, 1979. However, because of early delays encountered at all locations, the program was extended for an additional week. The last day of operations in the Pacific was February 20; 71 round-robin sorties were flown from Hickam AFB and 26 from Howard AFB. A total of 1739 dropwindsondes were launched. Thanks to the flexibility demonstrated by the USAF in accomplishing the sudden change of operating locations at the beginning of the SOP and, above all else, the skill, professionalism, and dedication of the aircrews, system operators, and ground support personnel, the first SOP was operationally a success.

2.3 SOP-2

The agreement between the WMO and the GOM for use of Acapulco International Airport was finally signed on April 24, 1979, and diplomatic notes between the GOM and the U.S. were exchanged the next day. For the first time all barriers to the full implementation of the original plan for the Dropwindsonde Program in the Pacific were removed. The shuttle flights between Hawaii and Mexico could be flown and unbroken longitudinal coverage of the Eastern Pacific could be provided. (The text of the agreement and the Protocol of Execution are reproduced at the end of this section of Chapter 6.)

The first of two C-141s landed at Acapulco in the early afternoon of May 8. To all those who had suffered through the frustrations and uncertainties of the first SOP, it was an emotional moment. In accordance with the agreement with the GOM, all national emblems had been removed from the aircraft; only a small WMO emblem and an aircraft number were displayed on the tail. The second aircraft arrived one hour later. Two similarly marked aircraft arrived at Hickam AFB on the same day.

The second SOP started well when, according to schedule on May 10, the first shuttle flight to Hawaii from Acapulco was launched along with round-robins from both locations. The second day, May 11, went equally well when the shuttle

was launched from Hickam AFB to return to Acapulco and two more round-robins were flown according to plan. The first two days were 100 percent; only 28 more to go for a perfect record. It was a week later before we had another 100-percent day, and overall we would only experience 15 days when the Pacific dropwindsonde program was 100 percent according to plan.

The vulnerable point in the plan was Acapulco, where every other day there was only one aircraft available for launch, and where repair facilities and logistic support were minimal for C-141s. It was, however, a known vulnerability and a calculated risk necessitated by the resources available to the program. Of the three tracks to be flown daily in the Pacific, the P-10 round-robins from Acapulco were the most vulnerable. When aircraft or observing system problems prevented a take-off on those days when only one aircraft was available, the sortie would be missed for the day. Further, even on those days when two aircraft were available, if one failed, priority was given to launching the shuttle to Hawaii, and the P-10 track would be missed. The shuttle was not only important for its scientific value; it was essential for logistic support to Acapulco. During the 30 days of operations for SOP-2, the P-10 or P-11 tracks were missed 14 times.

The Hickam-Acapulco shuttle tracks were missed on only one day (May 22) and the westward round-robin from Hawaii was flown every day. On the one day the shuttle was missed, a special westward round-robin (P-15) was flown, along with an eastward round-robin from Hawaii (P-30 FLOP). This combination of round-robins longitudinally covered all but 5 degrees of the shuttle track. Hence, except for those 5 degrees on the 22nd of May, the Pacific program provided longitudinal coverage in the active region from 100°W to the date-line every day.

A total of 81 of a planned 90 mission sorties were flown in the Eastern Pacific during SOP-2. While 14 planned sorties along the P-10 series of tracks were lost, five unplanned sorties were gained by utilizing the fourth or spare aircraft. 90% of the planned number of sorties were flown and 1518 dropwindsondes were launched (83% of those planned).

At Acapulco, any concerns the U.S. participants may have had about the degree of Mexican support and cooperation, in view of the long and difficult negotiations, were very quickly put to rest. The Mexican representatives showed a keen interest in the program and lent encouragement and assistance well beyond that required by the Protocol of Execution.

APPENDIX 1

TRANSLATION

AGREEMENT ON THE GLOBAL WEATHER EXPERIMENT

BETWEEN

THE WORLD METEOROLOGICAL ORGANIZATION

AND

THE GOVERNMENT OF MEXICO

CONSIDERING that the World Meteorological Organization is planning a Scientific Experiment relating to the meteorological and oceanographic processes on the global scale within the framework of the Global Atmospheric Research Programme (GARP) of the Organization and the International Council of Scientific Unions;

CONSIDERING that Mexico is situated in proximity to areas in which special aircraft operations will be conducted as part of the Experiment and has at its disposal the appropriate installations, and that it has therefore been recommended that an aircraft operational centre of the Experiment should be established at Acapulco;

CONSIDERING that the Government of Mexico has considered with interest this recommendation;

NOW THEREFORE the following agreement is concluded as the basis for the co-operation between the World Meteorological Organization and the Government of Mexico.

Section 1 - Name of Experiment

The Experiment shall be known as the Global Weather Experiment, hereinafter referred to as "the Experiment".

Section 2 - Purpose of the Experiment

- To obtain a better understanding of atmospheric motion for the development of more realistic models for weather prediction.

- To assess the ultimate limit of predictability of weather systems.

- To design a composite meteorological observing system for routine weather prediction of the larger-scale features of the general circulation of the atmosphere.

- To investigate, within the limits of the period of observation as provided for in this Agreement, the physical mechanisms underlying

the fluctuations of climate in the time range of a few weeks to a few years and to develop and test appropriate climatic models.

- In order to meet the above objectives, an instrument package will be dropped via parachute from an aircraft, and the instruments will measure winds and temperature and humidity profiles over tropical sea areas of the Pacific Ocean. Such data will be made available to all Member States of WMO as indicated in the WMO FGGE Publication Series: FGGE Report No. 3 - the FGGE Data Management Plan.

Section 3 - Conduct of the Experiment

The Experiment shall be conducted by National Co-operating Agencies designated by the Member States of the World Meteorological Organization indicated in the WMO FGGE Publication Series, Implementation and Operational Plan for the FGGE Special Observing Systems: Part B: Aircraft Dropwindsonde System, in co-operation with the World Meteorological Organization, hereinafter referred to as "the Organization". Member States of the Organization, other than Mexico, participating in the Experiment are hereinafter referred to as "other participating Member States".

Within the framework of the present Agreement the Organization shall be responsible for the implementation of the Experiment. The Organization will neither accept nor endorse any financial liability that might result directly or indirectly from the implementation of the Experiment. This liability will be the responsibility of the participating Member States.

Section 4 - Duration of the Experiment in respect of the aircraft operations

Aircraft operations will be conducted during the Period of intensive Observations which is scheduled to take place from 10 May 1979 to 8 June 1979.

Section 5 - Co-operating Agencies

The designated Co-operating Agencies under the present Agreement shall be:

(a)	For the World Meteorological Organization:	The Secretariat of the Organization
(b)	For Mexico:	Foreign Affairs Secretariat; National Defense Secretariat; Finance and Credit Secretariat; Agriculture and Water Resources Secretariat; The Secretariat for Communications and Transport and for Airports and Auxiliary Services.
(c)	For the other participating Member States:	Such national agencies as the Member States shall designate in accordance with Section 16 below.

Section 6 - Privileges and Immunities

The Government of Mexico grants to the personnel participating in the Experiment the privileges and immunities as set forth in Article VI of the Convention on Privileges and Immunities of the United Nations with the reservations made by the Government of Mexico as ratified by it in the Official Journal of the Federation of 10 May 1963.

Section 7 - Authorization for Access to and Use of Facilities in Mexico

The Government of Mexico authorizes for the Period of Intensive Observations of the Experiment, with additional time prior to and after this period for the appropriate preparation and termination procedures, the use, in so far as practicable, by other participating Member States of the facilities of Acapulco Airport as may be required during the duration of the Experiment, in accordance with Section 4, and as they appear in the Protocol of Execution attached to the present Agreement.

Section 8 - Entry and Departure of Aircraft and Personnel

(a) The Government of Mexico shall, upon request which should be made 72 hours in advance, take the necessary steps to grant in due time the authorization for entry into and departure from Mexico during the Experiment in respect of the aircraft with the emblem of the Organization and personnel of the other participating Member States assigned to the Experiment.

(b) The Government of Mexico reserves the right to verify the identity of personnel assigned to the Experiment and to inspect equipment, materials and instruments which will be used during the Experiment.

Section 9 - Importation and Exportation of Materials, Equipment, Supplies, Goods and other Property

The Government of Mexico shall, upon request, and in accordance with the Convention on Privileges and Immunities of the United Nations, take the necessary steps to authorize the admission without restriction into Mexico for use during the Experiment and in due course, where appropriate, the removal from Mexico, of materials, equipment, supplies, goods and other property of any other participating Member State.

Section 10 - Fiscal Exemptions

Materials, equipment, supplies, goods and other property, including motor vehicles, belonging to the other participating Member States, assigned to Mexico for the purpose of the Experiment, and imported into Mexico for use during the Experiment, shall, on request and in accordance with the Convention on Privileges and Immunities of the United Nations, be admitted free of tax, customs and import duties and other charges, subject to exportation after the conclusion of the Experiment. Detailed lists of such property shall be sent to the Co-operating Agencies of Mexico designated in Section 5.

Section 11 - Landing Fees and Other Similar Charges

No fees shall be payable by participating Member States for aeronautical activities in Mexico for the purpose of the Experiment. However, the cost of services rendered in respect of the use of equipment and special facilities shall be reimbursed in accordance with customary rates.

Section 12 - Expenditures and Payments

All expenditures and payments resulting from the execution of the present Agreement and relating to the provision of services to the participating Member States or their designated Co-operating Agencies shall be entirely borne by those Member States.

Section 13 - Liability

(a) Each Co-operating Agency of a participating Member State shall be responsible for claims for damage to property or injury to persons with respect only to activities directly related to the Experiment or performed by the Co-operating Agency or its employees.

(b) Whenever an employee of a Co-operating Agency is involved in a personal capacity in any litigation, the Co-operating Agency shall collaborate with Mexican authorities to facilitate settlement of the litigation.

(c) This Agreement will not come into force for any Co-operating Agency of any other participating Member State until it has signed an Agreement on liability between the Government of the said other participating Member State and the Government of Mexico.

Section 14 - Settlement of Disputes

(a) Any dispute between the Government of Mexico and the Organization relating to the application or interpretation of the present Agreement shall be settled by negotiation or by any other mode of peaceful settlement of disputes agreed on by the parties.

(b) For any dispute of a similar nature arising between another participating Member State and the Organization or between Mexico and any other participating Member State or between participating Member States the procedure detailed in (a) above shall be adopted *mutatis mutandis* unless otherwise provided for in a specific arrangement agreed upon between the parties concerned or in a note by which a Member State agrees to be a participating Member State as provided for in Section 16 (a) below.

Section 15 - Protocol of Execution

The Organization shall negotiate with the Mexican Government for signature a Protocol of Execution which, in accordance with this Agreement, shall relate to the details of implementation of the present Agreement applicable to each participating Member State, and shall constitute an annex thereto.

Each Member State of the Organization shall receive a copy of this Protocol of Execution.

Section 16 - Application of this Agreement to Participating Member States

(a) In order that this Agreement and the Protocol of Execution may become applicable to any of the other participating Member States of the Organization, that Member State shall deliver to the Government of Mexico a note wherein the Member State agrees to be a participating Member under the terms and conditions prescribed in the Agreement and in the Protocol of Execution and specifying the name and address of its national agency which will act as its Co-operating Agency for the purposes of the Agreement, as soon as it has fulfilled the stipulations of Section 13 (c). The Organization shall receive a copy of the note.

(b) Any of the other participating Member States may, if necessary, establish with the Government of Mexico, Supplementary Arrangements, which, in accordance with the present Agreement, shall specify any further administrative and technical details of the required co-operation between the two Governments.

The Organization shall receive a copy of such Supplementary Arrangements.

(c) Such Supplementary Arrangements shall constitute annexes to this Agreement, applicable only to the parties concerned.

(d) Any Supplementary Arrangements may be amended at any time, by mutual agreement between the two parties concerned. Any amendments shall be notified to the Organization.

(e) Any specific arrangement made in accordance with the provisions of the present Agreement shall constitute an annex to this Agreement, applicable only to the parties to the arrangement.

Section 17 - Notification of Annexes and Amendments

The Organization shall notify all participating Member States of all annexes and amendments established in accordance with the provisions of Sections 15 and 16.

Section 18 - Duration of Agreement

(a) This Agreement shall enter into force upon signature by both parties and shall remain in force until the Government of Mexico and the Organization mutually determine that the Experiment has been completed, but in all events the Agreement shall terminate not later than 30 June 1979.

(b) This Agreement shall enter into force for other participating Member States on the date of notification of their acceptance thereof in

accordance with Section 16 (a) above, after they have fulfilled the terms and conditions indicated therein, and will terminate in accordance with Section 18 (a).

Done and signed at Geneva on this twenty-fifth day of April nineteen hundred and seventy-nine

For the
Government of Mexico

(Signature)
Permanent Representative of Mexico
with the international organizations
in Geneva

Roberto Martinez Le Clainche
Ambassador

For the
World Meteorological Organization

(Signature)
Secretary-General

D. A. Davies

Certified that the above text in the English language is an authentic translation of the original text in the Spanish language.

Geneva, 25 April 1979

(Signature)

(L. Colson)
Chief, Language Branch,
WMO Secretariat

(Signature)

(D.A. Davies)
Secretary-General, WMO

APPENDIX 2

TRANSLATION

PROTOCOL OF EXECUTION

Pursuant to the provisions of Section 15 of the Agreement on the Global Weather Experiment between the World Meteorological Organization and the Government of Mexico;

The Government of Mexico, and the World Meteorological Organization, hereinafter referred to as the "Organization";

Have agreed as follows:

Article 1 - Conduct of the Experiment

(a) Each participating Member State shall detach in Acapulco Airport during the Experiment a representative to co-ordinate activities on the spot and to establish liaison with the Mexican Co-operating Agency, which, for the purpose of the execution of the present Protocol relevant to the Government of Mexico, shall be duly designated.

(b) The Organization shall co-ordinate its activities through the FGGE Operations Centre at the WMO Secretariat, Geneva. The main duties of the FGGE Operations Centre shall be to ensure that the planning and conduct of the Experiment are directed at all times toward the achievement of the scientific goals of the Experiment.

(c) The Government of Mexico shall likewise designate a qualified person as Liaison Officer who will be the contact for the representatives and the Organization.

(d) The main duties of the representative shall be:

i) to ensure the provision of the operational, administrative and logistic support needed to achieve the scientific objectives of the Experiment;

ii) to provide the scientific guidance required for the flight operations from the operations site;

iii) to be the focal point for liaison with the Mexican Co-operating Agency concerning all personnel, operational, administrative and logistic aspects of the programme;

iv) to co-ordinate the scientific aspects of the programme with the Mexican Co-operating Agency and the participation of authorized Mexican personnel in the programme of in-flight operations.

(e) The schedule of operations at Acapulco Airport shall be as follows:

Personnel

Arrival not earlier than 1 May 1979
Departure not later than 15 June 1979

Aircraft

Arrival not earlier than 5 May 1979

Planned departure around 10 June 1979, with possible extension up to 15 June 1979 should aircraft maintenance and/or FGGE observational programme so require.

(f) All participating aircraft shall undergo customs and health inspection upon landing in Acapulco.

(g) All the operations of participating aircraft shall be subject to the legal provisions for aviation.

(h) The representatives of other participating Member States shall provide the Mexican representative with the operations schedule before each flight from Acapulco as well as a report of the programme accomplished immediately after each flight terminating in Acapulco.

(i) In the aircraft being used for the Experiment, no arms, photographic or remote sensing equipment are permitted, whether installed in, or carried aboard these aircraft.

(j) Aircraft used in the Experiment are required to display the emblem of the Organization. No other emblem shall be used. The use of the emblem of the Organization, of its name and of abbreviations of that name through the use of its initial letters by any Member State participating in the Experiment is formally authorized for the purposes of this Experiment by the Secretary-General of the Organization. The said aircraft shall not be subject to the registration under laws or regulations of Mexico.

Article 2 - Personnel matters

(a) Personnel from other participating Member States shall obtain the appropriate visas prior to the commencement of operations, and shall be subject to the Mexican immigration regulations.

(b) The Government of Mexico reserves the right to determine the number of the personnel of the other Member States participating in the Experiment.

(c) Lists of participating personnel shall be exchanged between the representatives as well as information on any amendments thereto.

(d) Appropriate provisions shall be made for authorized Mexican personnel to participate in the flight programme. Up to three authorized Mexican persons shall participate in each flight. Matters relating to the Mexican personnel participating in the flight operations shall be co-ordinated between the representatives.

(e) Personnel participating in the operations of the Experiment shall not wear military uniform.

Article 3 - Hospital and Medical Services

The Mexican Co-operating Agency shall:

(a) Provide information on the hospital services and premises, as needed.

(b) Provide a list of the names, addresses and telephone numbers of recommended doctors and dentists in private practice in Acapulco.

Article 4 - Specific Undertakings on the Part of the Mexican Co-operating Agency

(a) The Mexican Co-operating Agency shall assist the other participating Member States with regard to the following:

i) the necessary arrangements for using offices and hangar space at Acapulco Airport;

ii) authorization for access to and use of facilities at Acapulco Airport;

iii) entry and departure of aircraft and personnel to and from Mexico;

iv) importation and exportation of materials, equipment, supplies, goods and other property needed for the Experiment;

v) fiscal exemptions in accordance with Sections 9, 10 and 11 of the Agreement on the Global Weather Experiment between the World Meteorological Organization and the Government of Mexico.

(b) The Mexican Co-operating Agency shall, in so far as practicable, arrange for the provision of:

i) free parking space at Acapulco Airport for a fleet of up to three C-141 aircraft to be used in the Experiment;

ii) such amounts of open storage space at Acapulco Airport as may be required for the storage of equipment and supplies intended for use in the Experiment. This space shall not exceed 200 square meters.

Article 5 - Specific Undertakings on the Part of the Organization

(a) The Organization shall arrange that the other participating Member States, either jointly or individually and for the duration of the operations except as otherwise provided above, or as may be agreed at some future date, shall provide, or arrange for the provision of the aircraft, all the technical equipment and supplies and all the personnel required for the conduct of the Experiment.

(b) The Organization shall maintain at its Secretariat in Geneva, Switzerland, an FGGE Operations Centre for the international co-ordination of the Experiment.

Article 6 - Term

The present Protocol of Execution shall enter into force upon signature by both parties and shall be coterminous with the Agreement on the Global Weather Experiment between the World Meteorological Organization and the Government of Mexico.

The present Protocol of Execution shall enter into force for other participating Member States on the date of notification of their acceptance thereof, in accordance with Section 16 (a) of the Agreement on the Global Weather Experiment and, upon fulfilment of the terms and conditions laid down therein, shall terminate on 30 June 1979.

Done and signed at Geneva on this twenty-fifth day of April nineteen hundred and seventy-nine

For the
Government of Mexico

Permanent Representative of Mexico
with the international Organizations
in Geneva

Roberto Martinez Le Clainche
Ambassador

For the
World Meteorological Organization

Secretary-General
D. A. Davies

Certified that the above text in the English language is an authentic translation of the original text in the Spanish language.

(Signature)

(L. Colson)
Chief, Language Branch,
WMO Secretariat

(Signature)

(D. A. Davies)
Secretary-General, WMO

CHAPTER 7

DROPWINDSONDE OPERATIONS

PART 2: THE ATLANTIC

By
J. Smalley (NCAR)

1. INTRODUCTION

The FGGE aircraft dropwindsonde program included flights from Ascension Island in the South Atlantic Ocean. A track was flown, generally east along 7.5 degrees south latitude and west along 2.5 degrees south latitude (Figure 4 in Part 4 of this chapter). Ascension Island is a British possession used extensively for radio and undersea cable communications. The United States also maintains a facility there, mainly for satellite tracking. The writer was designated the FGGE Director of Operating Location 4 (OL-4), i.e., Ascension Island. This chapter is a report of FGGE Atlantic Ocean dropwindsonde operations from his viewpoint.

2. SUMMARY OF OPERATIONS

During SOP-I, a single WC-135 was on station at OL-4 for dropwindsonde operations. A variety of maintenance problems prevented the planned second aircraft from ever joining the operation and higher priority national requirements precluded the reassignment of another WC-135 to Ascension Island for FGGE SOP-I operations.

The one aircraft which operated at OL-4 during SOP-I arrived on station one week late because of maintenance difficulties which, unfortunately, continued to plague the operation throughout the SOP. The aircraft only flew 11 times during the 29 days it was on station. It turned out that the supply pipeline was too long for timely repairs. Certain one-of-a-kind failures occurred simply due to the age of the C-135 fleet. The failure causing the greatest number of lost days was a cracked cockpit side window. For these and other reasons, the U.S. FGGE Project Office decided to try to replace the single SOP-I C-135 with two C-141s for SOP-II operations. Fortunately, the Air Force was able to agree to this request.

During SOP-II, while there were some maintenance problems with the C-141s, only two scheduled flights were missed and one of these was made up later. Overall, the SOP-II operations were excellent, and Atlantic area dropwindsonde operations from OL-4 achieved the highest SOP-II mission accomplishment percentage of the three areas covered by FGGE dropwindsondes.

The following table summarizes OL-4 operations for the two SOPs and clearly shows the dramatic improvement of SOP-II compared to SOP-I. (NOTE: Part 4 of this chapter gives a more detailed summary including depiction of actual tracks flown.)

Drop Summary of SOP-I and SOP-II

SOP	Number of Missions Flown	Number of Sondes Dropped
I	11	205
II	29	546

3. DROP STRATEGY

Drop strategy differed somewhat from the other OL's. This was brought about by the fact that Ascension Island was directly on the mission track. As soon as the aircraft took off, it was time to drop the first sonde. For best coverage all the way around the track, it was desirable to have 350 km between the last drop and first or, lacking that, not to exceed 500 km. All of this could have been accomplished by a spiral ascent at the start followed by the first sonde drop. Then as Ascension was approached, the last drop could be followed by a loiter (without turns) until impact and then a spiral descent to the Island. However, this plan was precluded by permissable fuel load limitations and crew fatigue considerations. (The runway length and slope, and emergency braking requirements limited take-off weight and fuel load.) Accordingly, take-off was immediately followed by climb to altitude in a straight line. The first sonde was dropped on passing through 25,000 feet. Succeeding sondes followed at a nominal spacing of 350 km. In practice the last drop was made when the aircraft was quite near the island. To minimize the flight time, the drop was followed by a gradual deceleration and slow descent. To preclude loss of a signal, descent rate was limited so that the aircraft was still above 25,000 feet when the sonde reached the surface. This usually meant that the island was overflown.

In the drop sequence, if a turn was imminent the drop was delayed until the turn was complete. If a turn was required while a sonde was in the air -- the usual case -- the turn was held to a 10-degree bank. Past experience with GATE data reduction showed that maneuvers at either the beginning or end of a drop are more difficult to smooth accurately so an attempt was made to accomplish all maneuvers (turns, altitude, changes, speed changes) in middrop.

4. ON-THE-GROUND PROCEDURE

The desire to space the first and last drops no more than 500 km apart caused a change in preflight procedures at Ascension. It was most important that the first drop be made as soon as possible. This meant that the first sonde had to be baselined while the aircraft was still on the runway. There was a difficulty imposed by this requirement. Late in aircraft preflight, there came a point where power was switched from external power to internal power. This switchover generally disrupted the onboard systems and meant restarting the computer and Omega synchronization. Loss of the computer meant loss of any preflight baselining. Thus, it was necessary to establish a procedure that, even though the aircraft was ready, it should not leave the chocks until the ODWS was ready and the first sonde baselined. This sometimes produced anxiety in the minds of the flight crews, because in routine Air Force operations, aircraft readiness is all important. When the aircraft is ready-- it goes. Any upsets or failures compounded the problem. Nevertheless, in the research environment, the scientific requirements of the experiment were made to take precedence.

5. PERFORMANCE OF THE DROPWINDSONDE AT OL-4

During SOP-I, almost every OL-4 sonde was checked for proper removal of the timer and chute cover because of start-up problems with the mechanical assembly. The manufacturer was promptly notified of the items being discovered and remedial action was taken. One of the most prevalent difficulties resulted from a rubber packing band binding the drogue. Although the drogue could not open, it would still stream behind the sonde and the timer would very likely be started. If the chute cover was at all tight, the undeployed drogue would not be able to pull it off and the sonde would be a "fast fall". If the cover was not tight, it would most likely be shaken out and the chute deployed, since it was packed in such a way that very little force was needed to pull it from the chute cavity. Even though the undrogued sonde would be falling rapidly, experience during development test drops showed that the main chute would probably survive opening impact. The other most prevalent occurrence was an excessively tightly fitting chute cover which would not release, resulting in a fast fall even though the drogue did work properly.

Even after the above problems were corrected, there continued to be a disappointing number of fast falls during the early stage of SOP-I. When it was clear that the problem was not sonde-assembly or launch-operation related, launching sondes nose first was tried with a considerable improvement in launch successes. The C-135 has an extraordinarily long launch tube extending down from the cabin floor. It appears that during the long fall in the tube, the cap was coming off before the sonde left the tube so that the drogue was already partially deployed upon leaving the tube and subsequently not opening properly.

Most sondes launched by Ascension aircraft passed the temperature and humidity calibration checks prior to launch, but many failed the pressure check. Surprisingly, most sondes reported a pressure lower than the reference pressure (cabin pressure). While cabin pressure varied with altitude, it was very steady during level flight. Further work needs to be done in this area to pinpoint the cause and the remedy for the apparent anomolous pressure readings. However, in accordance with the FGGE instructions, failure to pass the pressure check was not usually considered cause for rejecting the sonde, since the thermodynamic parameters were far less important than the wind data.

During a flight with a laboratory pressure standard on board, it was discovered that the reference pressure output does not change as rapidly as cabin pressure. It is probably a case of a large software filtering time constant. Consequently, the word was passed to all OLs that baselining should not take place during change in altitude. A printout of reference pressure was available so the operator could watch it until the value stabilized.

Approximately half of the sonde drops were coded in TEMP DROP code and transmitted by voice to the WWW Global Telecommunications System. A drop that had few "reasonable" winds was not transmitted and the next drop used. If a drop yielded only a few unreasonable winds, it was coded, omitting the levels where the winds were unreasonable. The judgment of reasonableness was, of course, subjective. After a couple of days or more of flying, one could get a feeling for the expected values.

Although one of the levels to be coded was 1000 mb, the real-time system cannot give a wind measurement at this level. The winds reported are at the mid-point of a four-minute window. The data used for the 1000-mb level are distorted because much of the window occurs after impact. The post-processed winds do not suffer from this limitation; however, it would be a significant programming task to change the algorithm to report a real-time wind close to the time of impact.

The TEMP DROP code called for surface values of pressure, temperature, and dew point depression, which were difficult to measure accurately. The real-time system reports every ten seconds; thus surface data reported may contain some values collected after impact. Also the data are noisy as impact generally occurs at maximum range. A considerable improvement in estimation of impact would be possible. There is a meter showing received signal strength. As the drops nears the surface, the meter reading is usually very low, but it sometimes clearly shows impact. The Omega signals can be heard with a pair of ear phones and impact can often be detected by the change in the signal character. In the system used during FGGE, there was no way to relate these to the printed output. If, when impact was imminent, the operator could turn on a strip chart and record P, T, H, Omega, signal strength and time, then splash down could almost always be detected. With time known, an extrapolation of the printed data could result in greatly improved surface values. In a more sophisticated implementation, one would store data in memory and display it in some fashion. The human capability of the operator would be used to decide the instant of splash down and the computer would calculate smoothed values at that time.

6. PERFORMANCE OF THE AIRCRAFT ON-BOARD SYSTEM

At the outset, it should be emphasized that the aircraft on-board systems had many important improvements over the first-generation system during GATE in 1974. A great number of aids were supplied to prompt the operator at each step in the drop sequence. Many steps were interlocked to ensure necessary supporting data were entered on the recording tape. Several self-test features were used.

Particular to the installations for FGGE, the on-board system had the fallback option of manually entering Heading and True Air Speed. During the latter part of SOP-I, the TAS signal was lost and the manual option was very valuable.

In a sense, the operator of any on-board system is operating blind. One does not really know if the system is working properly. That is, the question "Are the winds being reported correctly?" cannot be answered. There were some aids, however. First of all, one could listen to the Omega signals. In the Atlantic it was always comforting to hear Liberia come blasting through loud and clear. It was always easy to check synchronization. On the runway on Ascension, one could often hear five, and sometimes seven stations. The onboard system had the convenient feature of listing all the Omega stations, on command, and a measure of their "quality". While it was not a positive indication, one at least knew when real-time winds were bad or doubtful and knew they should not be reported. There was a direct and observable correlation between poor quality signals and unreasonable winds.

Two other signals were available to see "how goes it". On command one could print the flight-level wind. It is, as the name implies, the wind vector computed by the aircraft channel of the dropwindsonde system as the difference between the reported TAS and Heading and the movement of the aircraft through the Omega field of signals. It was not uncommon for this computed flight-level wind to diverge from that reported from the Inertial Navigation System. It was not clear what was going wrong, and there was no way to set in a best estimate -- say from the INS. Instead, it was necessary to halt operation and go through the tedious steps of entry of NAVigation MODE followed by TAS, HEADING, MAGnetic VARiation, LATitude, LONGitude, DATE, and TIME. When in a hurry, it was never possible to enter latitude and longitude precisely, which probably contributed to new errors in flight-level winds.

On command, one could also print the oscillator frequency error. It was never expected to be zero but ideally should be a small constant value. In the laboratory, such a condition was routinely achieved. In flight this was almost never the case. The operators were instructed to observe the oscillator fairly often and zero it out when needed. Fortunately, the single command, OSC, sufficed. The error estimate could be entered also, but experience showed that zero was as good a value as any. It wasn't going to stay where you put it anyway. This particular entry was rather abstruse to the operators and would probably be better monitored and corrected by the computer itself.

The culprit causing diverging flight-level wind and oscillator frequency error was most likely disturbances of the Omega signals. It is hard to see how a high-flying, constant-speed, constant-altitude platform such as an aircraft could be the problem. Of course, the aircraft does change its geometric position within the field and flight-level winds do change, but these changes are not as drastic as indicated in the on-board system output.

7. CONCLUSIONS AND FUTURE RECOMMENDATIONS

The low percentage of missions flown at OL-4 during SOP-I was at least largely due to the absence of the planned second aircraft. Higher priority missions precluded the assignment of a substitute aircraft when maintenance problems prevented the second aircraft from joining the operation. The fact that FGGE could not compete successfully for this necessary resource highlights an inherent difficulty in conducting a research program with operationally justified platforms. The OL-4 SOP-II operations went fine, so such problems are certainly not inevitable. However, planners of future programs should remember that research activities are less vulnerable to short-notice developments if they are not dependent on the use of military platforms.

DROPWINDSONDE OPERATIONS

PART 3: THE INDIAN OCEAN

By
J. McFadden (NOAA/RFC)

1. INTRODUCTION

In the shadow of the Equator, at 7°20'S and lying halfway between Indonesia and the African Coast at 72°25'E, the island of Diego Garcia became the site of the Research Facilities Center's Indian Ocean Dropwindsonde Operations in support of the Global Weather Experiment (FGGE). Geographically, Diego Garcia was the ideal location from which to launch double sorties daily during the two Special Observing Periods (SOPs). It is most unlikely that either the extensive area covered or the number of missions flown could have been accomplished from any other location in the Indian Ocean area.

From the beginning of the FGGE planning phase, it was evident that a centrally located Indian Ocean base was essential to the operation. Several other locations could have been utilized at significantly higher costs and with considerably greater difficulty. These included Singapore to the east, Sri Lanka to the north, and the Seychelles to the west. Any one of these alone would not have been suitable to obtain full coverage of the Indian Ocean and splitting the available resources between two of the locations would have resulted in an operational, logistical, and communications nightmare. Diego Garcia was clearly the best choice.

2. DIEGO GARCIA - THE ISLAND, ITS HISTORY, AND THE PRESENT FACILITIES

In 1966, the United Kingdom and the United States signed a bilateral agreement making the island available to the two countries as a midocean communications base. Construction of the communications station, the airport, and the permanent base facilities by a Naval Marine Construction Battalion began in 1971 and continues unabated at present with fuel storage facilities, a deep water port, and permanent housing for all personnel.

Today, Diego Garcia is a thriving community of over 1500 U.S. Navy personnel and about 25 officers and enlisted personnel from the British Royal Navy. While the base is almost exclusively used for U.S. military endeavors, the island is still part of the British Indian Ocean Territory and under United Kingdom jurisdiction. A Royal Navy officer oversees the island. The other British officers and men for the most part work along with the U.S. Navy personnel on the base. Customs, police activities, etc., all come under the purview of the British Representative and his staff.

The permanent party of the U.S. Navy group on Diego Garcia is made up of the Navy Communications Station, the Navy Support Facility, which provides personnel to support air and ship operations, billeting, food service, etc., and the Naval Marine Construction Battalion, which handles all heavy construction underway on the island.

Located four miles from the town and a short distance south of the fuel storage area is Diego International Airport. To say that this was a complete and modern airfield would not be fair to those who operated there during FGGE. Certainly, the runway was long enough, even though a parallel taxiway did not exist, and the aircraft parking apron was large enough in most situations. The personnel in air operations, weather, and communications were talented and quite eager, and the working atmosphere was congenial. Beyond these things, there were many problems.

Fueling was a major headache. Although there were three fueling pits, only one fuel line existed which had as its maximum pump rate a flow of 500 gallons per minute with one aircraft being fueled. Add a second aircraft and the flow dropped to 250 gallons per minute.

There were no hangars at the airfield in which to perform heavy maintenance during extremely hot or inclement weather. Ground support equipment was in such heavy use and poor condition that long periods of maintenance downtime for this equipment were required. Special tools for aircraft maintenance were often not available on the island and had to be flown in from the Philippines. In a few instances, unnecessary delays resulted. For example, in order to change an engine, it was necessary to order a crane (if it was available) from the motor pool, have it driven to the field, and use it to hoist the engine away from its mount.

3. THE PLANNING PHASE

It was clear that in order for our operation to be a success, a great deal of effort and care would have to go into the planning phase. Negotiating with the Department of Defense and the United Kingdom for use of the island facility, making arrangements for support of the aircraft at Diego Garcia as well as other bases between there and Miami, arranging housing, messing, and transportation for the 35 NOAA employees on the island, logistics, communications, enroute over-flight and landing clearances, etc., all had to be considered and carefully worked out. With the cooperation of the U.S. FGGE Project Office, in particular Mr. Onial Thomas, the U.S. Navy, especially CDR. Del Ritchhart, and the U.S. Air Force, the planning and preparation for our operation went very smoothly.

Negotiations for the use of Diego Garcia were initiated in March 1976 with tentative approval from the Navy Department being issued in July of that year. Final confirmation of its availability was given in April 1978. Once NOAA had obtained these necessary clearances, it was then possible to deal with the U.S. Navy in planning the required support on the island for the RFC operation.

Preliminary contacts were handled by the FGGE office and arrangements were made for an on-site visit in September 1978 by NOAA personnel to discuss support requirements. During this trip, discussions were held with Pacific Fleet personnel in Pearl Harbor, Hawaii, and with officers from various support groups at Cubi Point Naval Air Station in the Philippines.

During this period of time, parallel efforts were underway in Miami by the RFC supply section to arrange shipment of spares and supplies by military airlift to Diego Garcia. As the shipping point for our supplies was Travis AFB, it was necessary to devise a method of getting them to California and onto a MAC flight along with minimizing the possibility that individual packages might become separated during transit or even disappear. The solution was to construct plywood containers which could be loaded with supplies for shipment and then used on the island for their storage. One pallet size and two quarter-pallet size boxes solved our problem. Transfer to Travis AFB was accomplished by truck.

For OL-3, Diego Garcia, the plan called for two flights per day from a total of three aircraft, two WP-3Ds and one WC-130B. Flight duration was approximately ten hours for the P-3s and nine hours for the C-130. Our daily operating plan called for rotating the aircraft, thereby maintaining a schedule of two days up and one day down. While it would have been more desirable for FGGE program objectives to fly the P-3s as often as possible because of their longer range, follow-on projects (MONEX, EPOCS, and the Australia Tropical Cyclone Program) dictated equal distribution of flight time among all three aircraft. Accordingly, the aircraft operations section of RFC prepared an operations plan that took into account local conditions. Deployment and redeployment plans, communications, safety, etc., were also included in this document.

4. THE EXECUTION - SOP-I

Between the completion of the planning phase and the beginning of the operational phase at Diego Garcia, several events of major significance occurred which severely impacted the early part of SOP-I. An understanding of the availability of RFC resources at this time is necessary to explain the relatively poor performance during the first days of the experiment.

Around the middle of December, the C-130 was flying its last mission prior to the holidays and our planned 5 January departure for the FGGE. During this short system test flight, the aircraft suffered a catastrophic failure of its #2 engine. The first stage of the turbine exploded, blowing away the clamshell doors, causing severe damage to the engine mount, and cutting several gashes in the fuselage section of the aircraft. Preliminary estimates on the time required to obtain parts, to build up the engine with a new turbine section, to replace the engine mount, and to repair the fuselage section was one month, particularly considering labor problems over the holiday period. The aircraft was repaired and departed Miami on 18 January, or two weeks later than originally planned.

One P-3, N42RF, had participated in the Winter MONEX program in Malaysia during November and December and because of a needed phase inspection and the total flight hour commitment for the FGGE and the follow-on Australia program, RFC elected to store the aircraft at Cubi Point, NAS, in the Philippines over the holiday break and to return there on 5 January to begin a normal five- to seven-day phase inspection. Unexpected maintenance problems, such as fuel leaks, a prop seal leak, and a cracked center fuel tank cover plate produced a delay in the departure date. This was further complicated by clearance problems for Singapore resulting in a delay in the arrival of N42RF at Diego Garcia until 18 January.

As a consequence of these two events, RFC began SOP-I at OL-3 with one aircraft, N43RF, and about 20 people. We quickly revised our operating plan to fly single missions with one P-3 starting on the 15th and double missions beginning on the 18th after the second P-3 arrived. This was not to be.

On 17 January, N43RF suffered a failure of the turbine stage of the #2 engine and we were quickly introduced to the rather painful experience of

maintaining an aircraft at a facility where neither tools nor spare engines are kept on location. Nine days after our request for a replacement engine went out, we finally received shipment. Two days later, we were back in the air.

The remaining portion of SOP-I was relatively uneventful from an operational point of view. True, we did have a gear box failure on N42RF which also necessitated an engine change, but the logistics system was primed by then and we were back in the air in less than half the time for N43RF.

During SOP-I, the Naval Weather Service Environmental Detachment at Diego Garcia had the capability of receiving only the Japanese GOES satellite which provided coverage of the Indian Ocean area east of the island. Weather information west of the island was derived from ship and aircraft reports. The principle tracks covered during SOP-I are shown in Figure 5 in Part 4 of this Chapter. In all, 61 missions were flown during the period.

On 20 February, NOAA secured its operation on Diego Garcia and departed the island for Singapore. From Singapore, one P-3 went to Australia for the Tropical Cyclone Project and the other P-3 went to Guam to begin the Equatorial Pacific Ocean Climate Study. The C-130 returned to Miami.

5. THE BREAK PERIOD

During the two-month break period between phases, primary attention was given to analyzing our performance during SOP-I with an eye to improving our operation. One of the major areas of concern was the inadequate housing the NOAA personnel had during the first phase of the project. Aside from the lack of air conditioning, the communal type living in cramped quarters created a serious morale problem near the end of the period. After working and eating with your co-workers, it was also then necessary to sleep along side of them. There was simply no privacy to be had.

In attempting to obtain better quarters for SOP-II, we were made aware that naval activities were on the upswing in the Indian Ocean and, if indeed we were permitted to return to Diego Garcia in May, the quarters that we would be assigned would be even more austere than we had during SOP-I.

This was considered by RFC to be unacceptable and after consulting with the FGGE Project Office, the process of trying to obtain clearance to operate the second phase from Sri Lanka was initiated.

Although NOAA did obtain permission from the government of Sri Lanka to operate from that location, the decision was made after much thought and discussion to return to Diego Garcia and make the best of the situation. RFC did go through the process of drawing up a contingency operations plan for Sri Lanka in the event it was necessary to use it at any time during SOP-II.

6. THE EXECUTION - SOP-II

All three aircraft were scheduled to depart for Diego Garcia on Tuesday, 1 May, with intermediate stops in California, Hawaii, Guam, and Singapore. On Friday, 27 April, ten minutes before the end of the business day, RFC received a call from Lockheed Aircraft Company indicating that all P-3s had been grounded pending an inspection for cracks in the support brackets in the outboard fuel tanks. The procedure required defueling of the aircraft, opening and airing the tank with blowers, and inspecting the support brackets. Upon completion of the inspection, the tank was to be resealed and refueled.

The entire process required at least two days per aircraft, particularly in our situation where outside contractors and subcontractors play a key role in accomplishing the work. As the alarm was sounded after RFC and contractor personnel had departed for the weekend, no useful work began until 30 April. This resulted in one aircraft, the C-130, leaving on schedule on 1 May followed by one P-3 on each of the two following days. Arrival in Diego Garcia was also staggered with one aircraft arriving on each of three days beginning on 8 May.

Other than an engine failure on N42RF and complications because of the increased Fleet activity, SOP-II was fairly routine. The NWSED was receiving TIROS-N data during this period and the satellite information was very useful for track selection. Toward the latter part of the observing period, several attempts were made to coordinate our flights with the Summer MONEX flights originating in Bombay. For the most part, owing to communications difficulties, this was unsuccessful. Primary flight tracks are shown in Figures 8 and 9.

Operations on Diego Garcia were secured on 9 June with the departure of the C-130. All spare parts and unused supplies were prepared for shipment by MAC prior to our departure. Subsequent airlift to Miami occurred without any problem.

7. OMEGA GROUND MONITORING STATION

In support of the FGGE and under the direction of Dr. S. A. Rossby, RFC established an OMEGA receiving station on Diego Garcia to monitor the quality of the OMEGA signals. The purpose of the monitoring was threefold:

(1) To detect transmitter outages;

(2) To detect and note times of anomalous propagation, and;

(3) To detect and note times of phase anomalies resulting from Sudden Ionospheric Disturbances (SID).

Each of the above have the potential of seriously degrading the quality of wind measurements made by the OMEGA Dropwindsonde System (ODWS).

With regard to numbers (1) and (2) above, if the effect is severe, there is nothing to be done but flag the questionable data. In the case of a SID (3), there was some thought that we might be able to model the effect of the disturbance with the ground station and apply some correction to the affected wind measurements. However, very few SIDs of any consequence were observed in SOP-I and II. Therefore, no corrections will be attempted as the effort is not warranted.

The receiving system consisted of two Tracor 599-R OMEGA navigation receivers, a Tracor 304-D rubidium frequency standard, and a Wintronics MIIE multipoint strip chart recorder.

Using the frequency standard as a reference, the phase of each received signal was plotted on the chart recorder. Data obtained during the two SOPs were sent to NCAR as were all other data obtained during the experiment.

8. CONCLUSIONS AND RECOMMENDATIONS

The success of our mission in the Indian Ocean can only be attributed to the hard work of a dedicated group of people. Regardless of how poor operating conditions are, there is still a tremendous sense of pride among the individuals in the organization to demonstrate that the job can be done. Add to this a certain inter-plane rivalry that exists in RFC and you end up with a healthy operational situation. I think the results of these were clearly demonstrated in the FGGE.

If the question ever arose as to whether RFC would return to Diego Garcia for a follow-on program, the answer would be yes. (This is not to say that another location would be more preferable to our personnel.) Within the next year or so, the construction of permanent quarters will be completed and air-conditioned spaces will be available for all visitors to the island. Additional facilities, including a hangar and new fueling systems, are being constructed at the airport, and the complete ground support facility is being upgraded to handle a much heavier load of air traffic.

The major recommendation I would make if a follow-on program is planned is to utilize four aircraft in the operation. While RFC was reasonably successful in meeting program objectives with three aircraft, the burden was quite heavy considering the lengthy downtime experienced on three separate occasions when an aircraft required an engine change. A 100 percent mission achievement would be within the realm of probability with the additional aircraft.

As a final comment, it should be pointed out that the island is a beautiful place. The Navy personnel we worked with, both British and American, were understanding and very cooperative. There was a mutual support understanding among all of the aircraft operators whereby we all helped each other. I am happy to say that NOAA's presence saved the day on several occasions for both the ASW P-3s and the S-3A from the "MIDWAY". Then, too, they saved us a number of times.

The experience of being on Diego Garcia was a memorable one. To have missed it would have been disappointing, but no one seems to be in a hurry to return.

Table 1.--Diego Garcia - Significant events SOP-1

DATE	EVENT
January 5	N43RF departs Miami
January 13	N43RF arrives in Diego Garcia
January 13	N42RF is in Cubi Point because of maintenance delays
January 15	N43RF begins SOP-I. N42RF delayed because of clearance problems
January 17	N43RF loses #2 engine because of turbine failure. Mission completed
January 17	N42RF departs Cubi Point - cracked nose wheel noted during refueling in Singapore
January 18	N42RF arrives in Diego Garcia
January 18	C-130 departs Miami
January 19	Single missions resume
January 26	C-130 arrives in Diego Garcia
January 27	Daily double sorties commence
January 28	N43RF in commission
February 3	N42RF aborts due to gear box failure of #2 engine. Engine change required because necessary stands and engine supports are unavailable on island.
February 8	N42RF in commission
February 8	C-130 loses pressurization six (6) hours into the flight. Major portion of mission was completed.
February 10	C-130 - Bleed air duct rupture mission aborted
February 18	N42RF departs Diego Garcia for Singapore
February 20	N43RF and C-130 depart Diego Garcia

Table 2.--OL-3 Diego Garcia - Significant events SOP-11

DATE	EVENT
May 1	C-130 N6541C departs Miami
May 2	N42RF departs Miami
May 3	N43RF departs Miami
May 8	C-130 arrives in Diego Garcia
May 9	N42RF arrives in Diego Garcia
May 10	SOP-II operations begin; N43RF arrives in Diego Garcia
May 15	C-130 grounded by hydraulic leak
May 16	N43RF flies modified N40 track with termination in Colombo, Sri Lanka. Stopover was made to test feasibility of conducting operations from that location should it be necessary.
May 17	C-130 hydraulic line part obtained from USS CAMDEN, Seventh Fleet support ship
May 17	N42RF loses #1 engine. Navy was reluctant to release on-site T56-14 engine to NOAA
May 21	C-130 down because of broken stud on oil scavenger pump
May 22	C-130 problem corrected with assistance from Naval Marine Construction Battalion
May 25	Daily cable to MONEX Office, Bombay initiated containing OL-3 FGGE flight schedule
May 29	Engine change on N42RF completed
May 31	Northeast corner of track N31 truncated because of Seventh Fleet operations in that area
June 3	N42RF "buzzed" by A-4 based on carrier USS MIDWAY
June 7	N42RF departs Diego Garcia for Singapore
June 8	N43RF departs Diego Garcia for Bangkok
June 9	C-130 departs Diego Garcia for Singapore. FGGE mission at OL-3 terminated

Table 3.--OL-3 Diego Garcia - NOAA participants

POSITION	NUMBER
OL-FGGE Director	1
Pilots	8
Navigators	4
Flight Engineers	6
Mechanics	4
Loadmaster (C-130)	1
ODW Operators and Electronics Maint.	8
Supply	1
Engineering Technician	1
Avionics Technician	1

CHAPTER 7

DROPWINDSONDE OPERATIONS

PART 4: FLIGHT TRACK AND MISSION SUMMARY

By
O. Thomas
(NOAA/OA1)

1. INTRODUCTION

This summary of flight tracks and missions flown is a supplement to the information provided in Parts 1, 2, and 3 of this Chapter. It is presented as a reference source for performance statistics and as a quick-look recapitulation of the accomplishments of the Aircraft Dropwindsonde Program (ADWP).

2. SOP-1 SUMMARY

The initial projection for SOP-1 was to fly a total of 180 dropwindsonde missions over the three oceans. 174, or 97%, were flown, although over a 37-day period rather than the originally scheduled 30 days. The 7 day extension was arranged because clearance difficulties and maintenance problems resulted in a slow start for the ADWP program. Only 24 missions were flown in the first 8 days vs 48 planned.

Clearance difficulties were most severe for the eastern Pacific base, where it finally became necessary to abandon original plans for SOP-1 operations out of Acapulco, Mexico. Instead, these operations were temporarily conducted from Norton Air Force Base in California and then moved to Howard Air Force Base, Panama Canal Zone for the duration of the SOP. Maintenance/aircraft availability problems were most serious at Ascension Island in the South Atlantic where only 37% of the planned number of missions were accomplished.

3. SOP-II SUMMARY

SOP-II ADWP operations started out much more smoothly than had been the case in SOP-I. Clearance problems with Mexico were resolved, and the utilization of Acapulco made possible a daily shuttle flight between Hawaii and the North American continent, thereby covering an oceanic region which had been data-void during SOP-I. Another crucial improvement was achieved in the Atlantic where the substitution of C-141 aircraft for the WC-135 used during SOP-I contributed to accomplishment of 97% of the planned missions during SOP-II. Overall for the four operating locations during SOP-II, 92% of the scheduled missions were flown during the 30-day operating period.

Table 1.--Summary of Aircraft Dropwindsonde Program - Global Weather Experiment - SOP-I

DATE 1979	Number of Missions	DROPWINDSONDES Number Launched	Number Collected Data	Number Reported on GTS	FLYING TIME (HOURS AND TENTHS)	REMARKS CALIFORNIA/ CANAL ZONE OL 1	HAWAII WEST OL 2	HAWAII EAST OL 2	DIEGO GARCIA EAST OL 3	DIEGO GARCIA EAST OL 3	ASCENSION OL 4
15 JAN	2	33	29	12	21.7	No Flight-Awaiting Diplomatic Clearance	Ground Abort			Only one A/C Maint.?	No A/C on station
16 JAN	3	31	28	14	26.7	" "		Air Abort		" "	" "
17 JAN	4	53	47	·26	39.5		Air Abort			" "	" "
18 JAN	3	35	31	15	29.7				A/C Maint. Problem	2nd P-3 on Sta.	" "
19 JAN	3	51	42	23	29.8	Equip. Inoperable				A/C Maint. Problem	" "
20 JAN	4	57	49	22	40.0		Air Abort			" "	" "
21 JAN	3	34	32	16	29.2	Stand Down for Move to Canal Zone	Air Abort			" "	" "
22 JAN	2	18	17	8	14.0	Moving to Canal Zone	Air Abort	Ground Abort		" "	WC-135 Arr. on Sta.
23 JAN	4	58	50	27	36.9			Air Abort Flying Time .0.8		" "	Air Abort
24 JAN	5	96	74	37	48.7					" "	
25 JAN	5	103	86	42	53.1					" "	
26 JAN	4	71	61	32	41.6					" " C-130 Arr. on Sta.	Crew Rest
27 JAN	5	85	72	36	50.5						A/C Maint. Problem
28 Jan	6	101	82	45	60.3						
29 Jan	6	96	84	41	58.1	Air Abort					
30 JAN	4	68	60	30	40.1	Equip. Probs.					A/C Maint. Problem
31 JAN	5	77	69	37	46.6		Air Abort				" "
1 FEB	5	82	77	43	51.6						" "
2 FEB	6	110	99	50	60.4						
3 FEB	6	99	89	45	58.5				Air Abort		
4 FEB	6	109	89	48	62.1						
5 FEB	5	88	74	38	51.6						Crew Rest
6 FEB	5	89	81	45	50.9						A/C Maint. Problem
7 FEB	5	90	83	48	50.7						" "
8 FEB	5	57	49	24	46.8		Air Abort		C-130 Air Abort		" "
9 FEB	5	88	82	41	50.3						" "
10 FEB	5	83	73	34	46.7				C-130 Air Abort		" "
11 FEB	5	92	82	43	50.4						" "
12 FEB	6	106	93	49	61.3						
13 FEB	6	115	101	48	63.0						
14 FEB	5	76	72	36	47.8		Air Abort				A/C Maint. Problems
15 FEB	6	106	94	54	59.4						
16 FEB	5	79	73	26	51.5						A/C Maint. Problems
17 FEB	5	76	68	30	47.2		Late T.O. Due to Maint. Problems				" "
18 FEB	5	*67	*65	*26	*40.5					Drops 500 km spacing	" "
19 FEB	5	81	76	34	50.6					" "	" "
20 FEB	5	67	65	21	43.2				2 Flights East to Singapore	No Flights West	" "
TOTAL	174	*2827	*2498	*1246	*1711.0						

*Data for P-3 Ferry Trip D.G. to Singapore Incomplete

Table 2.--Detail dropwindsonde operations Global Weather Experiment SOP-I California/Canal Zone OL-1

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	AA = Air Abort; AMD = Aircraft Mechanical Difficulty; EP = Equipment Problems (ODWS); NF = No flight; POS = Poor Omega Signals; TM = Track modified to avoid convection
			LAUNCHED	COLLECTED DATA	ON GTS		
15 Jan							Awaiting Diplomatic Clearance
16 Jan							Awaiting Diplomatic Clearance
17 Jan	C-141	P-01	11	11	6	11.2	Drops began 15S
18 Jan	C-141	P-02	11	10	4	11.3	Drops began 15S 1 streamer
19 Jan	C-141						NS; EP (Program would not load)
20 Jan	C-141	P-02	10	9	6	11.2	Minor EP
21 Jan	C-141						Stand down for move to Canal Zone
22 Jan	C-141						Moving to Canal Zone
23 Jan	C-141	P-03	18	16	9	10.3	
24 Jan	C-141	P-03	20	17	8	10.3	2 streamers
25 Jan	C-141	P-03	20	19	8	10.5	1 streamer
26 Jan	C-141	P-05	18	18	9	10.6	Minor EP
27 Jan	C-141		14	14	8	10.7	Special track to California
28 Jan	C-141		15	14	8	10.2	Special track to Canal Zone 1 streamer
29 Jan	C-141	P-05	9	8	4	8.6	AA (Program bombed repeatedly)
30 Jan	C-141						NF; EP (will not hold program)
31 Jan	C-141	P-05	21	20	14	10.9	Winds suspect on drops 14 thru 19
1 Feb	C-141	P-05	18	17	14	10.9	EP (cannot load calibration tapes)
2 Feb	C-141	P-05	19	14	10	11.0	EP (program bombs) 3 streamers
3 Feb	C-141	P-03	17	14	8	11.0	EP (program bombs)
4 Feb	C-141	P-03	14	10	8	11.2	EP (program bombs)
5 Feb	C-141	P-03	20	18	9	10.7	EP (program bombs) 2 streamers
6 Feb	C-141	P-03	20	19	16	10.9	EP (manual OP) 1 streamer
7 Feb	C-141	P-03	23	20	18	10.6	
8 Feb	C-141	P-05	10	8	5	11.2	EP (program bombs)
9 Feb	C-141	P-05	19	19	11	10.5	EP (tape reader/launcher)
10 Feb	C-141	P-03	21	21	10	12.0	I/C with Albrook EP
11 Feb	C-141	P-05	22	18	12	10.2	EP (manual) 3 streamers
12 Feb	C-141	P-05	12	10	8	10.4	EP (no baseline) 1 streamer
13 Feb	C-141	P-03	21	20	10	11.1	1 streamer
14 Feb	C-141	P-05	13	12	11	8.2	TM 1 streamer
15 Feb	C-141	P-05	22	19	17	11.1	EP
16 Feb	C-141	P-03	19	17	8	11.0	1 streamer EP (baseline)
17 Feb	C-141	P-05	20	17	11	11.0	TM
18 Feb	C-141	P-05	19	17	8	11.0	
19 Feb	C-141	P-05	19	19	11	10.5	
20 Feb	C-141	P-05	15	15	8	9.8	
TOTAL			530	480	297	330.3	

Table 3.--Detail dropwindsonde operations Global Weather Experiment SOP-1 Hawaii - East OL-2

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight POS = Poor Omega Signals TM = Track modified to avoid convection
			LAUNCHED	COLLECTED DATA	ON GTS		
15 Jan	C-141	P-30Flop	16	15	5	11.2	Last 7 drops suspect (convection)
16 Jan	C-141	P-31Flop	0	0	0	5.6	AA: EP (ant.)
17 Jan	C-141	P-31Flop	20	17	10	10.7	
18 Jan	C-141	P-30Flop	11	9	5	8.2	Strong head winds CWI. ATC CLNC. missed 9 drops for TAS corr
19 Jan	C-141	P-30Flop	20	17	9	10.5	CWI.
20 Jan	C-141	P-30Flop	18	14	4	10.6	CWI, 4 streamers
21 Jan	C-141	P-30Flop	17	17	8	11.0	Launch tube
22 Jan	C-141						Ground abort: AMD (primary & Spare)
23 Jan	C-141		0	0	0	.8	AA: AMD (unsafe nose wheel)
24 Jan	C-141	P-30Flop	20	18	10	9.0	Poor Omega signals on 12 drops
25 Jan	C-141	P-30Flop	21	17	8	11.2	EP (tape reader/strip chart printer)
26 Jan	C-141	P-30Flop	21	17	9	10.8	EP (slave teleprinter), 4 streamers
27 Jan	C-141	P-30Flop	23	19	8	11.1	
28 Jan	C-141	P-30Flop	14	12	7	11.1	CWI, 5 streamers
29 Jan	C-141	P-32Flop	18	18	10	11.4	
30 Jan	C-141	P-30Flop	17	17	8	10.9	
31 Jan	C-141	P-30Flop	20	20	10	11.3	
1 Feb	C-141	P-30Flop	22	20	10	11.2	
2 Feb	C-141	P-30Flop	23	23	11	11.4	EP (master printer)
3 Feb	C-141	P-30Flop	20	19	10	11.2	
4 Feb	C-141	P-30Flop	17	16	6	10.7	
5 Feb	C-141	P-30Flop	19	19	9	11.4	Some convection
6 Feb	C-141	P-30Flop	23	20	10	10.9	Flew at 4N to avoid Tahiti fir
7 Feb	C-141	P-30Flop	19	18	9	10.6	
8 Feb	C-141	P-30Flop	19	17	9	10.3	
9 Feb	C-141	P-30Flop	18	17	6	10.8	
11 Feb	C-141	P-30Flop	18	16	8	10.5	2 streamers
12 Feb	C-141	P-30Flop	20	20	10	11.2	
13 Feb	C-141	P-30Flop	19	18	6	10.9	1 streamer
14 Feb	C-141	P-30Flop	18	17	4	10.8	
15 Feb	C-141	P-30Flop	19	19	9	10.5	
16 Feb	C-141	P-30Flop	18	17	6	11.4	Flew S leg at 6N to avoid ITCZ
17 Feb	C-141	P-30Flop	15	14	6	10.4	
18 Feb	C-141	P-32Flop	20	20	7	9.5	
19 Feb	C-141	P-30Flop	18	17	9	11.5	
20 Feb	C-141	P-30Flop	17	16	5	9.8	
TOTAL			637	588	271	371.7	

Table 4.--Detail dropwindsone operations Global Weather Experiment SOP-I

Hawaii - West OL-2

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE LAUNCHED	DROPWINDSONDE COLLECTED DATA	DROPWINDSONDE ON GTS	FLYING TIME (HOURS AND TENTHS)	AA = Air Abort; AMD = Aircraft Mechanical Difficulty; EP = Equipment Problems (ODWS); NF = No flight; POS = Poor Omega Signals; TM = Track modified to avoid convection
15 Jan	C-141						Ground abort; EP (Omega out)
16 Jan	C-141	P-30	13	13	6	10.8	
17 Jan	C-141	P-30	5	4	2	7.0	AA; EP (Omega weak baseline inop)
18 Jan	C-141	P-30	13	12	6	10.2	Heavy cu west end
19 Jan	C-141	P-30	17	13	8	11.0	
20 Jan	C-141	P-30	11	10	5	6.9	AA; AMD (fuel valve)
21 Jan	C-141	P-30	5	4	2	7.4	AA; EP (Omega & Baseline prob)
22 Jan	C-141	P-30	2	2	1	4.1	AA; AMD (eng. inst. converter)
23 Jan	C-141	P-30	20	19	10	10.9	
24 Jan	C-141	P-30	20	15	6	10.6	EP (manual OP, 4 streamers)
25 Jan	C-141	P-30	22	20	11	10.7	
26 Jan	C-141	P-30	16	12	7	10.2	EP (Omega bad after drop 14, 2 streamers)
27 Jan	C-141	P-30	19	16	9	10.6	EP (manual only, 1 streamer)
28 Jan	C-141	P-30	22	17	10	10.7	
29 Jan	C-141	P-30	21	19	9	10.5	
30 Jan	C-141	P-30	19	18	10	10.2	
31 Jan	C-141	P-30	4	0	0	4.4	AA; EP (eng. hyd. leak)
1 Feb	C-141	P-30	14	14	7	10.1	EP; launch tube
2 Feb	C-141	P-30	20	20	9	10.3	
3 Feb	C-141	P-30	21	19	9	10.4	EP; launch tube
4 Feb	C-141	P-30	21	21	11	11.0	
5 Feb	C-141	P-30	19	15	9	10.7	4 streamers
6 Feb	C-141	P-30	19	18	9	10.5	
7 Feb	C-141	P-30	19	19	9	10.7	
8 Feb	C-141	P-30	2	0	0	6.0	AA; EP (computer out)
9 Feb	C-141	P-30	19	18	9	10.3	
10 Feb	C0141	P-30	21	18	7	10.5	3 streamers
11 Feb	C-141	P-30	19	19	9	9.8	
12 Feb	C-141	P-31	20	19	10	10.3	
13 Feb	C-141	P-31	20	18	9	10.1	1 streamer
14 Feb	C-141	P-30	14	14	7	8.8	AA; AMD (autopilot)
15 Feb	C-141	P-30	14	14	7	10.6	
16 Feb	C-141	P-30	15	14	0	9.9	Several deviations for Wx
17 Feb	C-141	P-30	11	11	4	7.5	Late T.O. for AMD; cut short for crew duty
18 Feb	C-141	P-30	18	18	6	10.3	
19 Feb	C-141	P-30	17	16	3	10.3	
20 Feb	C-141	P-30	20	19	5	8.3	
TOTAL			572	518	241	342.6	

Table 5.--Detail dropwindsonde operations Global Weather Experiment SOP-I

Diego Garcia - East OL-3

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight POS = Poor Omega Signals TM = Track modified to avoid convection
			LAUNCHED	COLLECTED DATA	ON GTS		
15 Jan	P-3	N-41	17	14	7	10.5	
16 Jan	P-3	N-41	18	15	8	10.3	
17 Jan	P-3	N-41	17	15	8	10.6	
18 Jan							NF-AMD (eng. chg) - 2nd P-3 arrives
19 Jan	P-3	N-45	14	12	6	8.3	
20 Jan	P-3	N-45	18	16	7	11.3	
21 Jan	P-3	N-45	12	11	6	10.8	P-3 flights will be reduced to 10 hrs
22 Jan	P-3	N-45	16	15	7	9.9	
23 Jan	P-3	N-45	16	14	7	10.2	
24 Jan	P-3	N-45	18	14	6	9.8	C-130 delayed in Singapore
25 Jan	P-3	N-45	18	15	8	10.0	
26 Jan	P-3	N-45	16	14	7	10.0	C-130 arrives on sta.
27 Jan	C-130	N-10	13	10	5	8.1	
28 Jan	C-130	N-10	14	12	6	9.3	
29 Jan	C-130	N-10	16	11	4	8.8	
30 Jan	C-130	N-10	16	10	5	8.9	2 additional drops good to 800 mb
31 Jan	P3	N-45	16	15	7	10.1	
1 Feb	C-130	N-10	12	11	5	9.3	AWRS inop - no flight level data
2 Feb	C-3	N-45	18	15	7	10.3	
3 Feb	P-3	N-45	5	3	2	6.3	AA - AMD (gear box failure)
4 Feb	C-130	N-10	15	12	7	8.5	
5 Feb	C-130	N-10	13	11	6	9.0	
6 Feb	C-130	N-10	11	11	5	8.7	EP (TTY failure)
7 Feb	C-130	N-10	11	11	6	8.7	
8 Feb	C-130	N-10	11	9	3	8.7	AA - AMD (pressurization)
9 Feb	P-3	N-45	13	13	7	8.7	
10 Feb	C-130	N-10	3	3	1	3.5	AA - AMD (pressurization)
11 Feb	P-3	N-45	15	14	7	10.1	
12 Feb	P-3	N-45	17	15	7	9.4	
13 Feb	P-3	N-45	15	15	8	10.1	
14 Feb	P-3	N-45	15	15	8	10.0	
15 Feb	C-130	N-10	14	11	6	8.8	
16 Feb	C-130	N-10	11	11	5	9.0	
17 Feb	C-130	N-10	13	11	4	8.5	
18 Feb	P-3	* 10	10	10	4	7.5	Special flight to Singapore
19 Feb	C-130	N-10	13	10	5	8.5	
20 Feb	C-130		7	7	1	7.9	Special flight DG to Singapore via 7.5S 95E
20 Feb	P-3		8	8	2	7.4	Special flight to Singapore via 2.3N 85E and 2.6N 98E
* Data for ferry trip DG to Singapore							
TOTAL			505	439	210	335.8	

Table 6.--Detail dropwindsonde operations Global Weather Experiment SOP-I

Diego Garcia - West OL-3

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight POS = Poor Omega Signals TM = Track modified to avoid convection
			LAUNCHED	COLLECTED DATA	ON GTS		
15 Jan							Only one a/c on station
16 Jan							Only one a/c on station
17 Jan							Only one a/c on station
18 Jan							Second P-3 arrived on station
19 Jan	P-3						AMD (engine change)
20 Jan	P-3						AMD (engine change)
21 Jan	P-3						AMD (engine change)
22 Jan	P-3						AMD (engine change)
23 Jan	P-3						AMD (engine change)
24 Jan	P-3						AMD (engine change)
25 Jan	P-3						AMD (engine change)
26 Jan	P-3						AMD (engine change); C-130 arr on sta
27 Jan	P-3	N-33	16	13	6	10.0	
28 Jan	P-3	N-33	15	15	8	10.2	Minor EP (tapedeck) tape may be bad
29 Jan	P-3	N-33	16	13	7	9.9	
30 Jan	P-3	N-33	16	15	7	10.1	
31 Jan	P-3	N-33	16	14	6	9.9	
1 Feb	P-3	N-33	16	15	7	10.1	
2 Feb	C-130	N-23	12	11	6	8.2	
3 Feb	P-3	N-33	17	16	7	10.3	
4 Feb	P-3	N-33	19	14	7	10.2	2 streamers - weak Omega
5 Feb	P-3	N-34	17	11	5	9.8	INE prob. - 1 streamer
6 Feb	P-3	N-34	16	13	5	9.9	
7 Feb	P-3	N-34	18	15	6	10.1	
8 Feb	P-3	N-33	15	15	7	10.1	
9 Feb	P-3	N-34	19	15	8	10.0	
10 Feb	P-3	N-34	19	13	6	9.9	No Omega 5 sondes - Omega weak
11 Feb	P-3	N-34	18	15	7	9.8	
12 Feb	P-3	N-34	16	14	7	9.8	
13 Feb	P-3	N-34	16	13	6	10.3	
14 Feb	P-3	N-34	16	14	6	10.0	
15 Feb	P-3	N-34	18	14	7	9.8	
16 Feb	P-3	N-33	16	14	7	10.2	
17 Feb	P-3	N-33	17	15	5	9.8	7 sondes no T&P - sensor cans empty
18 Feb	P-3	N-34	10	10	5	9.7	500 km spacing
19 Feb	P-3	N-34	14	14	6	9.8	500 km spacing
20 Feb							NF Both a/c to Singapore
TOTAL			388	331	154	237.9	

Table 7.--Detail dropwindsonde operations Global Weather Experiment SOP-I

Ascension OL-4

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight POS = Poor Omega Signals TM = Track modified to avoid convection
			LAUNCHED	COLLECTED DATA	ON GTS		
15 Jan							No aircraft on station
16 Jan							No aircraft on station
17 Jan							No aircraft on station
18 Jan							No aircraft on station
19 Jan							No aircraft on station
20 Jan							No aircraft on station
21 Jan							No aircraft on station
22 Jan							WC-135 arrives on station (1 crew)
23 Jan	WC-135	A-10	4	1	1	4.7	AA; EP
24 Jan	WC-135	A-14	18	10	7	8.8	Modified track to 9 hr so crew could fly 25 Jan
25 Jan	WC-135	A-14	22	15	7	10.7	
26 Jan	WC-135						Crew rest NF
27 Jan	WC-135						NS; AMD (bad battery)
28 Jan	WC-135	A-10	21	12	6	8.8	CWI - baseline
29 Jan	WC-135	A-10	16	15	7	8.9	1 streamer
30 Jan	WC-135						NF; AMD (hydraulic line broken)
31 Jan	WC-135						NF; AMD (hydraulic line broken)
1 Feb	WC-135						NF; AMD (hydraulic line broken)
2 Feb	WC-135	A-14	18	16	7	9.2	
3 Feb	WC-135	A-10	19	18	9	9.3	
4 Feb	WC-135	A-10	23	16	9	10.5	1 streamer
5 Feb	WC-135						NF; crew rest
6 Feb	WC-135						NF; AMD (cracked windshield)
7 Feb	WC-135						NF; AMD (cracked windshield)
8 Feb	WC-135						NF; AMD (cracked windshield)
9 Feb	WC-135						NF; AMD (cracked windshield)
10 Feb	WC-135						NF; AMD (cracked windshield)
11 Feb	WC-135						NF; AMD (cracked windshield)
12 Feb	WC-135	A-10	21	15	7	10.2	EP (TAS synchro failed)
13 Feb	WC-135	A-10	24	17	9	10.5	EP (TAS synchro failed) (1 tape head inop)
14 Feb	WC-135						NF; AMD (radar inop)
15 Feb	WC-135	A-10	19	17	8	8.6	EP (1 tape head inop)
16 Feb	WC-135						NF; AMD (hydraulic oump out)
17 Feb							NF; AMD (hydraulic pump out)
18 Feb							NF; AMD (hydraulic pump out)
19 Feb							NF; AMD (hydraulic pump out)
20 Feb							NF; AMD (hydraulic pump out)
TOTAL			205	152	77	100.2	

DATE 1979	PACIFIC OCEAN												ATLANTIC OCEAN		INDIAN OCEAN						
	P-01	P-02	P-03	P-04	P-05	P-30	P-30 Flop	P-31	P-31 Flop	P-32	P-32 Flop	Special C-7 to/from Calif.	A-10	A-14	N-10	N-23	N-33	N-34	N-41	N-45	Deployment to Singapore
15 Jan							X												X		
16 Jan						X			X										X		
17 Jan	X					X			X										X		
18 Jan		X				X	X														
19 Jan						X	X													X	
20 Jan		X				X	X													X	
21 Jan						X	X													X	
22 Jan						X														X	
23 Jan			X			X							X							X	
24 Jan			X			X	X							X						X	
25 Jan			X			X	X							X						X	
25 Jan					X	X	X													X	
27 Jan						X	X					X			X		X				
28 Jan						X	X					X	X		X		X				
29 Jan					X	X					X		X		X		X				
30 Jan						X	X								X		X				
31 Jan					X	X	X										X			X	
1 Feb					X	X	X								X		X				
2 Feb					X	X	X							X		X				X	
3 Feb			X			X	X						X				X			X	
4 Feb			X			X	X						X		X		X				
5 Feb			X			X	X								X			X			
6 Feb			X			X	X								X			X			
7 Feb			X			X	X								X			X			
8 Feb					X	X	X								X		X				
9 Feb					X	X	X											X		X	
10 Feb			X			X	X								X			X			
11 Feb					X	X	X										X			X	
12 Feb					X		X	X					X					X		X	
13 Feb			X				X	X					X					X		X	
14 Feb						X	X											X		X	
15 Feb					X	X	X						X		X			X			
16 Feb			X			X	X								X		X				
17 Feb					X	X	X								X		X				
18 Feb					X	X					X							X			X
19 Feb					X	X	X								X			X			
20 Feb					X	X	X														XX
TOTAL	1	2	11		15	34	31	2	2		2	2	8	3	15	1	12	11	3	16	3
OCEAN TOTAL	102												11		61						
																				TOTAL	174

Table 9.--Summary of aircraft dropwindsonde program

Global Weather Experiment SOP-II

DATE	NUMBER OF MISSIONS	NUMBER LAUNCHED	NUMBER COLLECTED DATA	NUMBER REPORTED ON GTS	FLYING TIME (HRS & TENTHS)	MEXICO OL 1	HAWAII OL2	SHUTTLE OL 1/2	DIEGO GARCIA EAST OL 3	DIEGO GARCIA WEST OL 3	ASCENSION OL 4
10 May	6	101	95	41	60.4				KL-DG		
11 May	6	94	83	35	61.1						
12 May	5	93	88	37	50.2	NF-AMD/EP					
13 May	5	89	81	38	51.2	NFEP/AMD					
14 May	5	78	67	27	49.0	NF-AMD					
15 May	4	53	48	22	37.5	NF-AMD	AA-EP				AA/GA
16 May	5	75	63	31	48.7	NF-AMD			to Colombo		
17 May	4	73	67	36	40.8	NF-EP				NF-AMD	
18 May	5	77	70	36	49.6	AA-Re-launch			return D.G.		NF-AMD
19 May	6	107	95	39	60.9						
20 May	6	101	91	46	61.9						
21 May	4	73	68	33	41.5	NF-AMD			NF-AMD		
22 May	5	96	89	45	51.9		2MSN	NF-AMD		NF-AMD	
23 May	6	86	83	41	53.4	AA-AMD					
24 May	6	104	96	46	60.1	NF-AMD		2MSNS			
25 May	6	106	98	59	61.2						
26 May	5	86	79	49	49.2	AA-EP					
27 May	4	64	57	36	39.3	NF-EP		NF-AMD/ EP			
28 May	5	87	79	49	49.2	NF-EP					
29 May	6	110	103	59	60.4						
30 May	6	102	91	44	61.0						
31 May	6	109	103	69	61.4						
1 June	6	109	103	54	60.7						
2 June	7	123	113	59	71.6			2MSNS			
3 June	6	97	91	48	57.8	NF-EVAC	2MSNS				
4 June	6	113	101	54	61.5	NF-EVAC	2MSNS				
5 June	6	104	98	58	58.4						
6 June	6	110	106	60	59.7			2MSNS	NF-AMD		
7 June	7	113	107	57	60.9						2MSNS
8 June	5	88	80	45	47.8					NF-AMD	
TOTAL	165	2821	2593	1353	1638.3						

Table 10.--Detail dropwindsonde operations Global Weather Experiment SOP-II

Acapulco, Mexico OL-1

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE LAUNCHED	DROPWINDSONDE COLLECTED DATA	DROPWINDSONDE ON GTS	FLYING TIME (HOURS AND TENTHS)	REMARKS AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight TM = Track modified
10 May	C-141	P-10	23	21	8	11.3	
11 May	C-141	P-10	19	19	9	11.3	
12 May	C-141		--	--	-	--	NF-AMD and EP
13 May	--		--	--	-	--	NF-AMD AND EP
14 May	--		--	--	-	--	NF-AMD
15 May	--		--	--	-	--	NF-AMD
16 May	--		--	--	-	--	NF-AMD
17 May	--		--	--	-	--	NF-EP
18 May	C-141	P-10	20	16	9	11.9	AA and relaunch
19 May	C-141	P-10	21	21	7	10.9	
20 May	C-141	P-10	20	20	8	10.8	
21 May	--		--	--	-	--	NF-AMD
22 May	C-141	P-15	20	18	8	10.4	
23 May	C-141	P-10	1	1	1	2.9	AA-AMD
24 May	--		--	--	-	--	NF-AMD
25 May	C-141	P-10	23	20	12	11.8	
26 May	--		--	--	--	--	AA-EP
27 May	--		--	--	--	--	NF-EP
28 May	--		--	--	--	--	NF-EP
29 May	C-141	P-10	21	21	11	11.0	
30 May	C-141	P-10	15	14	11	10.8	
31 May	C-141	P-10	22	21	18	10.8	
1 June	C-141	P-10	23	21	11	11.1	
2 June	C-141	P-11	18	17	9	10.8	TM
3 June	--	--	--	--	--	--	NO ACFT AVAIL DUE TO HURRICANE ANDRES
4 June	--	--	--	--	--	--	NO ACFT AVAIL DUE TO HURRICANE ANDRES
5 June	C-141	P-10	23	22	17	10.7	
6 June	C-141	P-10	20	20	10	10.3	
7 June	C-141	P-10	21	20	13	9.6	
8 June	C-141	P-10	20	20	10	10.8	
TOTAL		17	330	312	172	177.2	

Table 11.--Detail dropwindsonde operations Global Weather Experiment SOP-II Acapulco/Hawaii OL-1/2

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE LAUNCHED	COLLECTED DATA	ON GTS	FLYING TIME (HOURS AND TENTHS)	REMARKS AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight TM = Track modified
10 May	C-141	P-20	20	20	8	11.6	
11 May	C-141	P-20	20	20	6	10.6	
12 May	C-141	P-20	22	22	9	11.4	
13 May	C-141	P-20	23	20	8	11.1	TM
14 May	C-141	P-21	19	18	3	10.8	TM
15 May	C-141	P-21	19	18	7	10.6	
16 May	C-141	P-21	12	5	3	11.2	
17 May	C-141	P-20	21	18	15	10.8	
18 May	C-141	P-21	15	15	6	11.4	
19 May	C-141	P-21	21	20	8	10.5	
20 May	C-141	P-21	12	9	9	11.4	EP
21 May	C-141	P-20	19	19	10	10.6	
22 May	C-141	--	--	--	--	--	NF-AMD
23 May	C-141	P-22	18	18	10	11.2	
24 May	C-141	P-22	18	18	15	11.2	NOTE: 2 shuttles on 24 May
24 May	C-141	P-21	22	20	1	10.6	HF Radio problems
25 May	C-141	P-20	19	19	9	10.7	
26 May	C-141	P-20	19	17	6	10.2	
27 May	C-141	--	--	--	--	--	NF-1 a/c AMD, 1 a/c EP
28 May	C-141	P-21	18	18	11	10.8	
29 May	C-141	P-21	21	20	10	10.6	
30 May	C-141	P-21	20	19	4	11.5	
31 May	C-141	P-21	19	19	10	11.0	
1 June	C-141	P-21	20	20	10	10.9	
2 June	C-141	P-22	22	22	10	10.7	NOTE: 2 shuttles on 2 June
2 June	C-141	P-20	9	9	4	10.4	AA-AMD
3 June	C-141	P-22	18	17	8	10.0	TM
4 June	C-141	P-20	20	16	10	10.4	
5 June	C-141	P-22	20	20	12	10.6	
6 June	C-141	P-22	17	17	9	9.2	NOTE: 2 shuttles 6 June
6 June	C-141	P-21	17	17	15	10.6	
7 June	C-141	P-21	20	20	10	10.1	
8 June	C-141	P-21	20	17	11	9.6	
TOTAL		31	580	547	267	332.3	

Table 12.--Detail dropwindsonde operations Global Weather Experiment SOP-II Hawaii OL-2

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE LAUNCHED	DROPWINDSONDE COLLECTED DATA	DROPWINDSONDE ON GTS	FLYING TIME (HOURS AND TENTHS)	REMARKS AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight TM = Track modified
10 May	C-141	P-30	18	18	8	10.4	
11 May	C-141	P-30	15	7	6	10.6	
12 May	C-141	P-30	20	19	9	10.0	
13 May	C-141	P-30	19	18	9	10.7	
14 May	C-141	P-31	20	19	8	10.5	
15 May	C-141	P-31	4	4	2	7.9	AA-AMD/EP
16 May	C-141	P-30	19	17	8	10.7	
17 May	C-141	P-31	18	17	5	10.4	
18 May	C-141	P-30	20	17	10	10.3	
19 May	C-141	P-30	20	14	5	10.9	
20 May	C-141	P-30	19	19	8	10.5	
21 May	C-141	P-31	18	17	7	10.3	
22 May	C-141	P-30 F	20	19	12	10.9	NOTE: 2 RR 22 May
22 May	C-141	P-31	19	17	8	10.3	
23 May	C-141	P-30	19	19	5	10.6	
24 May	C-141	P-30	20	19	10	10.4	
25 May	C-141	P-30	18	18	18	10.4	
26 May	C-141	P-30	19	19	18	10.4	
27 May	C-141	P-30	16	15	15	10.3	
28 May	C-141	P-30	20	19	18	10.4	
29 May	C-141	P-30	19	17	14	10.5	
30 May	C-141	P-30	20	18	9	10.3	
31 May	C-141	P-32	20	19	17	11.0	
1 June	C-141	P-30	21	21	11	10.5	
2 June	C-141	P-30	21	19	11	10.0	
3 June	C-141	P-31	17	17	10	10.2	NOTE: 2 RR 3 June
3 June	C-141	P-31F	19	17	9	10.5	
4 June	C-141	P-30	20	20	9	10.7	NOTE: 2 RR 4 June
4 June	C-141	P-30F	20	19	9	10.7	
5 June	C-141	P-30	17	16	8	10.3	
6 June	C-141	P-30	18	17	9	10.3	
7 June	C-141	P-30	19	19	9	10.6	
8 June	C-141	P-30	16	15	10	10.0	
TOTAL		33	608	565	324	342.5	

Table 13.--Detail dropwindsonde operations Global Weather Experiment SOP-II

Diego Garcia - East OL-3

DATE	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	REMARKS AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight TM = Track modified
			LAUNCHED	COLLECTED DATA	ON GTS		
10 May	P-3	MOD N40	8	8	3	7.8	TM KL to DG
11 May	P-3	MOD N40	14	14	6	8.9	TM
12 May	P-3	N40	19	16	6	9.2	TM Wx in NW Quad
13 May	C-130	N12	11	10	6	8.7	
14 May	P-3	N40	10	4	3	9.0	EP TM
15 May	P-3	N40	16	12	6	9.2	TM
16 May	P-3	N40	10	10	5	6.5	DG to Colombo TM
17 May	P-3	N40	14	13	6	9.6	TM
18 May	P-3	N40	11	11	5	7.2	Colombo to DG TM
19 May	C-130	N12	13	11	6	9.2	
20 May	C-130	N12	14	12	6	9.0	
21 May	--	--	--	--	--	--	NF AMD
22 May	P-3	N44	15	15	8	9.7	TM
23 May	C-130	N12	13	12	6	8.9	
24 May	P-3	N44	16	13	7	9.8	TM
25 May	C-130	N12	12	11	5	9.0	
26 May	C-130	N12	11.	11	5	8.8	
27 May	P-3	N40	15	15	7	10.3	TM
28 May	P-3	N40	18	14	7	9.7	TM
29 May	P-3	N44	17	15	8	10.1	TM
30 May	P-3	N40	17	15	7	9.8	TM
31 May	P-3	N40	15	15	8	9.8	TM
1 June	P-3	N44	16	15	7	10.0	TM
2 June	P-3	N44	17	15	8	9.9	TM
3 June	P-3	N44	15	15	7	9.9	TM
4 June	P-3	N44	16	15	8	10.1	TM
5 June	P-3	N44	13	12	7	9.3	TM
6 June	--	--	--	--	--	--	NF-AMD
7 June	P-3	N40	10	10	5	7.5	DG to Singapore TM data estimated
8 June	P-3	N44	10	9	5	7.7	DG to Bangkok TM
TOTAL		28	386	348	173	254.6	

Table 14.--Detail dropwindsonde operations Global Weather Experiment SOP-II

Diego Garcia - West OL-3

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	REMARKS AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (OOWS) NF = No flight TM = Track modified
			LAUNCHED	COLLECTED DATA	ON GTS		
10 May	C-130	N20	14	12	6	9.0	
11 May	C-130	N20	11	11	1	9.0	
12 May	P-3	N35	14	14	6	9.3	
13 May	P-3	N35	14	14	7	9.7	
14 May	C-130	N20	15	13	6	9.1	
15 May	P-3	N35	14	14	7	9.8	
16 May	P-3	N35	15	13	6	9.5	
17 May	--	--	--	--	--	--	NF-AMO
18 May	C-130	N20	11	11	6	8.8	
19 May	P-3	N35	11	10	5	9.5	
20 May	P-3	N35	16	14	7	9.5	
21 May	P-3	N35	15	14	7	9.6	
22 May	--	--	--	--	--	--	NF-AMO
23 May	P-3	N35	14	14	7	9.5	
24 May	C-130	N23	12	11	6	8.3	
25 May	P-3	N35	15	14	7	9.3	
26 May	P-3	N35	16	12	7	9.6	
27 May	C-130	N20	12	11	6	8.7	
28 May	C-130	N20	12	12	5	8.8	
29 May	C-130	N22	12	11	5	8.2	
30 May	C-130	N20	14	10	5	8.8	
31 May	P-3	N31	12	12	7	8.8	TM
1 June	C-130	N23	10	10	5	8.7	
2 June	P-3	N30	15	13	7	9.8	TM
3 June	C-130	N20	8	8	4	7.6	TM
4 June	P-3	N35	15	13	7	9.6	TM
5 June	C-130	N22	10	10	5	7.5	TM
6 June	P-3	N35	16	14	8	9.3	TM
7 June	P-3	N35	14	14	8	9.4	TM
8 June	--	--	--	--	--	--	NF-AMO
TOTAL		27	357	329	163	244.7	

Table 15.--Detail dropwindsonde operations Global Weather Experiment SOP-II

Ascension OL-4

DATE 1979	AIR-CRAFT TYPE	TRACK FLOWN	DROPWINDSONDE			FLYING TIME (HOURS AND TENTHS)	REMARKS AA = Air Abort AMD = Aircraft Mechanical Difficulty EP = Equipment Problems (ODWS) NF = No flight TM = Track modified
			LAUNCHED	COLLECTED DATA	ON GTS		
10 May	C-141	A11E	18	16	8	10.3	
11 May	C-141	A11E	15	12	7	10.7	
12 May	C-141	A11E	18	17	7	10.3	
13 May	C-141	A11E	22	19	8	11.0	
14 May	C-141	A11E	14	13	7	9.6	EP
15 May	C-141	--	--	--	--	--	AA-AMD
16 May	C-141	A10E	19	18	9	10.8	
17 May	C-141	A10E	20	19	10	10.0	
18 May	C-141	--	--	--	--	--	NF-AMD
19 May	C-141	A11E	21	19	8	9.9	
20 May	C-141	A11E	20	17	8	10.7	
21 May	C-141	A11E	21	18	9	11.0	
22 May	C-141	A11E	22	20	9	10.6	
23 May	C-141	A11E	21	19	12	10.3	
24 May	C-141	A11E	16	15	7	9.8	
25 May	C-141	A11E	19	16	8	10.0	
26 May	C-141	A11E	21	20	13	10.2	
27 May	C-141	A13E	21	16	8	10.0	
28 May	C-141	A13E	19	16	8	9.5	
29 May	C-141	A13E	20	19	11	10.0	
30 May	C-141	A13E	16	15	8	9.8	
31 May	C-141	A14E	21	17	9	10.0	
1 June	C-141	A14E	19	16	10	9.5	
2 June	C-141	A14E	21	18	10	10.0	
3 June	C-141	A14E	20	17	10	9.6	
4 June	C-141	A14E	22	18	11	10.0	
5 June	C-141	A14E	21	18	9	10.0	
6 June	C-141	A14E	22	21	9	10.0	
7 June	C-141	A14E	15	13	7	7.0	TM NOTE: 2 RR 7 June
7 June	C-141	A14W	14	11	5	6.7	TM
8 June	C-141	A14E	22	19	9	9.7	
TOTAL		29	560	492	254	287.0	

Table 16.--Summary of flight tracks for the Global Weather Experiment SOP-II

DATE 1979	PACIFIC OCEAN											ATLANTIC OCEAN					INDIAN OCEAN									DAILY TOTAL
	P10	P11	P15	P20	P21	P22	P30	P31	P32	P30 FLOP	P31 FLOP	A14W	A10E	A11E	A13E	A14E	N35	N31	N30	N44	N40	N23	N22	N20	N12	
May 10	X			X			X							X							X			X		6
11	X			X			X							X							X			X		6
12				X			X							X			X				X					5
13				X			X							X			X								X	5
14					X			X						X							X			X		5
15					X			X									X				X					4
16					X		X						X				X				X					5
17				X				X					X								X					4
18	X				X		X														X			X		5
19	X				X		X							X			X								X	6
20	X				X		X							X			X								X	6
21				X				X						X			X									4
22			X					X		X				X						X						5
23	X					X	X							X			X								X	6
24					X	X	X							X						X		X				6
25	X			X			X							X			X								X	6
26				X			X							X			X								X	5
27							X								X						X			X		4
28					X		X								X						X			X		5
29	X				X		X								X					X			X			6
30	X				X		X								X						X			X		6
31	X				X				X							X		X			X					6
June 1	X				X		X									X				X		X				6
2		X		X		X	X									X			X	X						7
3						X		X			X					X				X				X		6
4				X			X			X						X	X			X						6
5	X					X	X									X				X			X			6
6	X				X	X	X									X	X									6
7	X					X	X					X				X	X				X					7
8	X				X		X									X				X						5
TOTAL	15	1	1	10	14	7	23	6	1	2	1	1	2	13	4	9	13	1	1	9	13	2	2	8	6	165
OCEAN TOTAL	81											29					55									

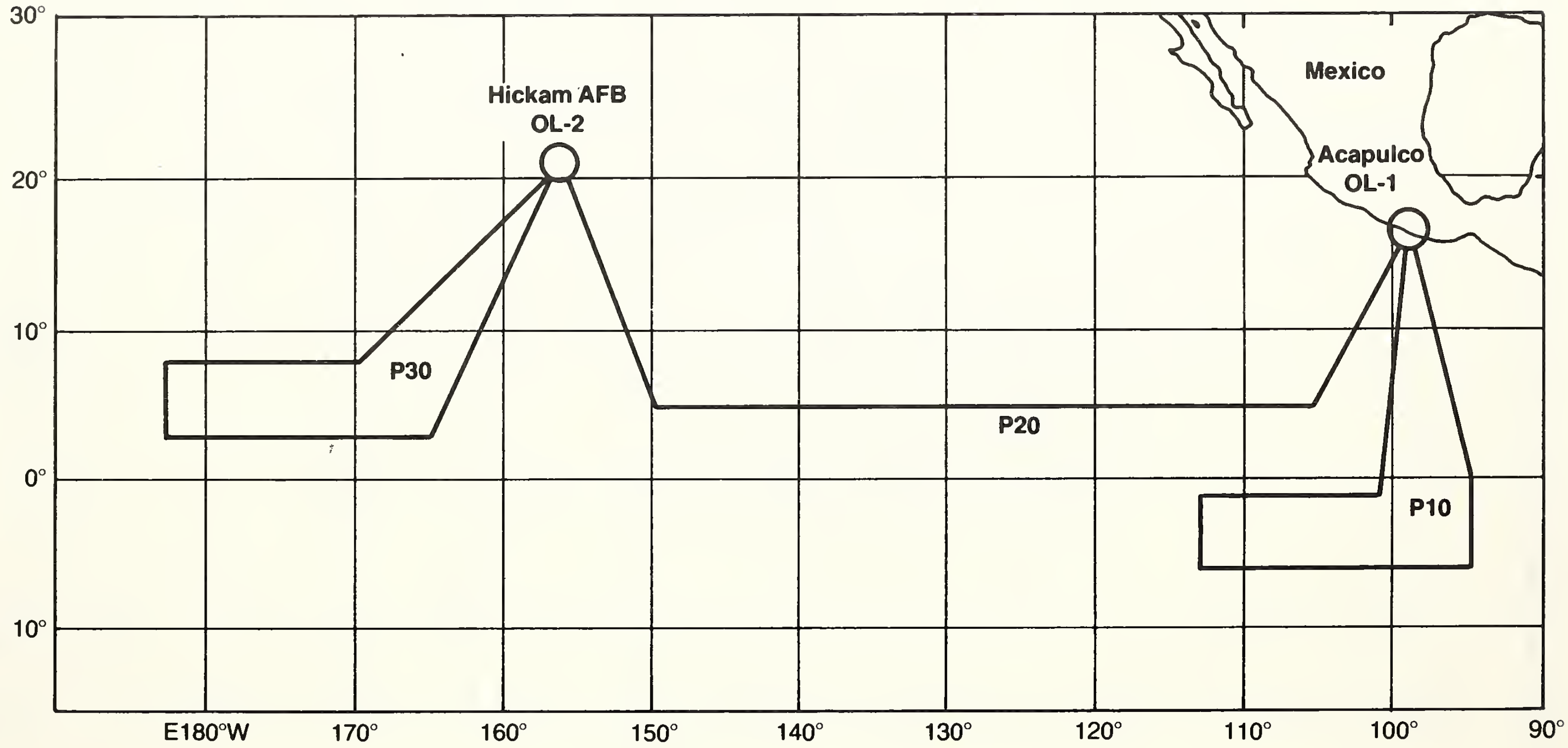

Figure 1.--Hickam/Acapulco shuttle and round robin "P" tracks.

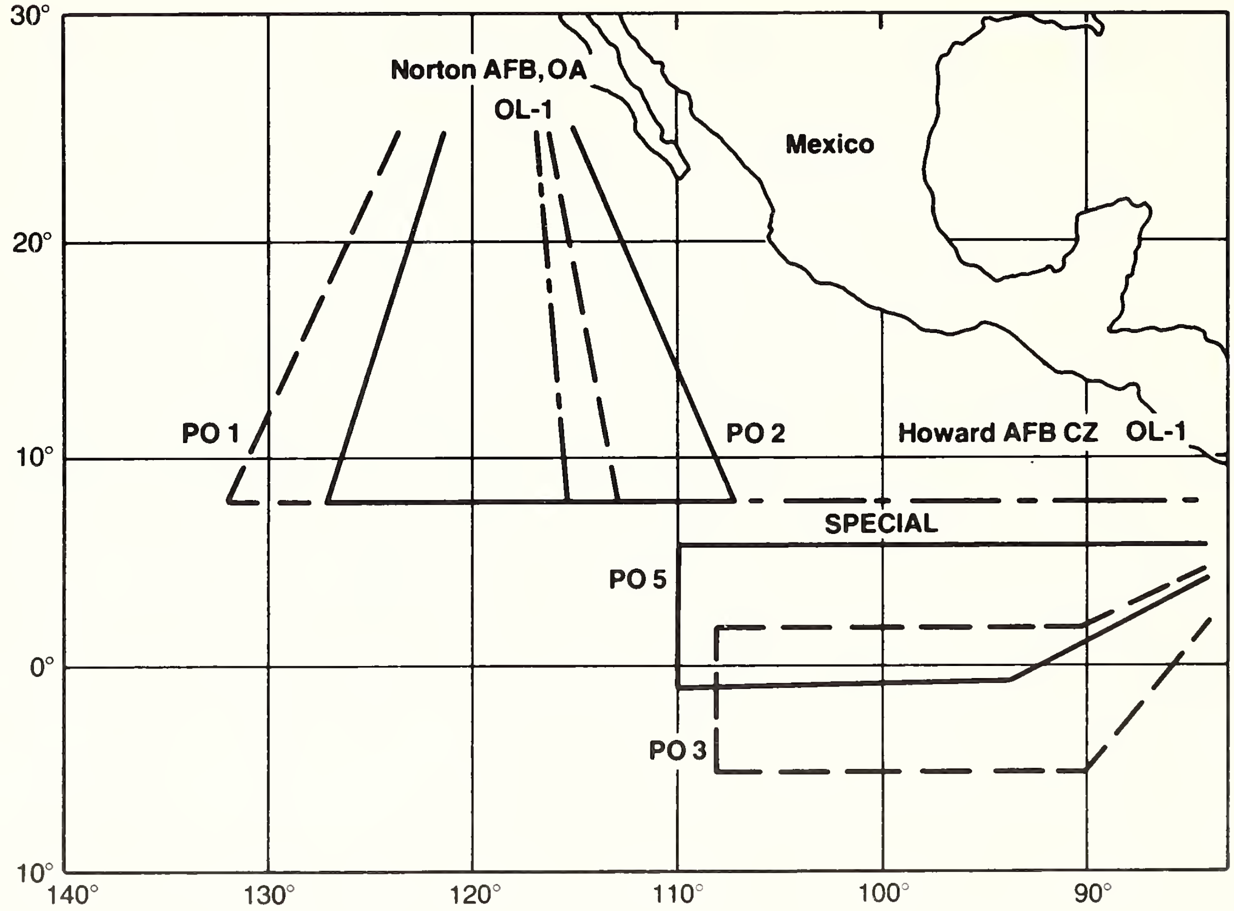

Figure 2.--Dropwindsonde flight tracks for FGGE SOP-I - Eastern Pacific

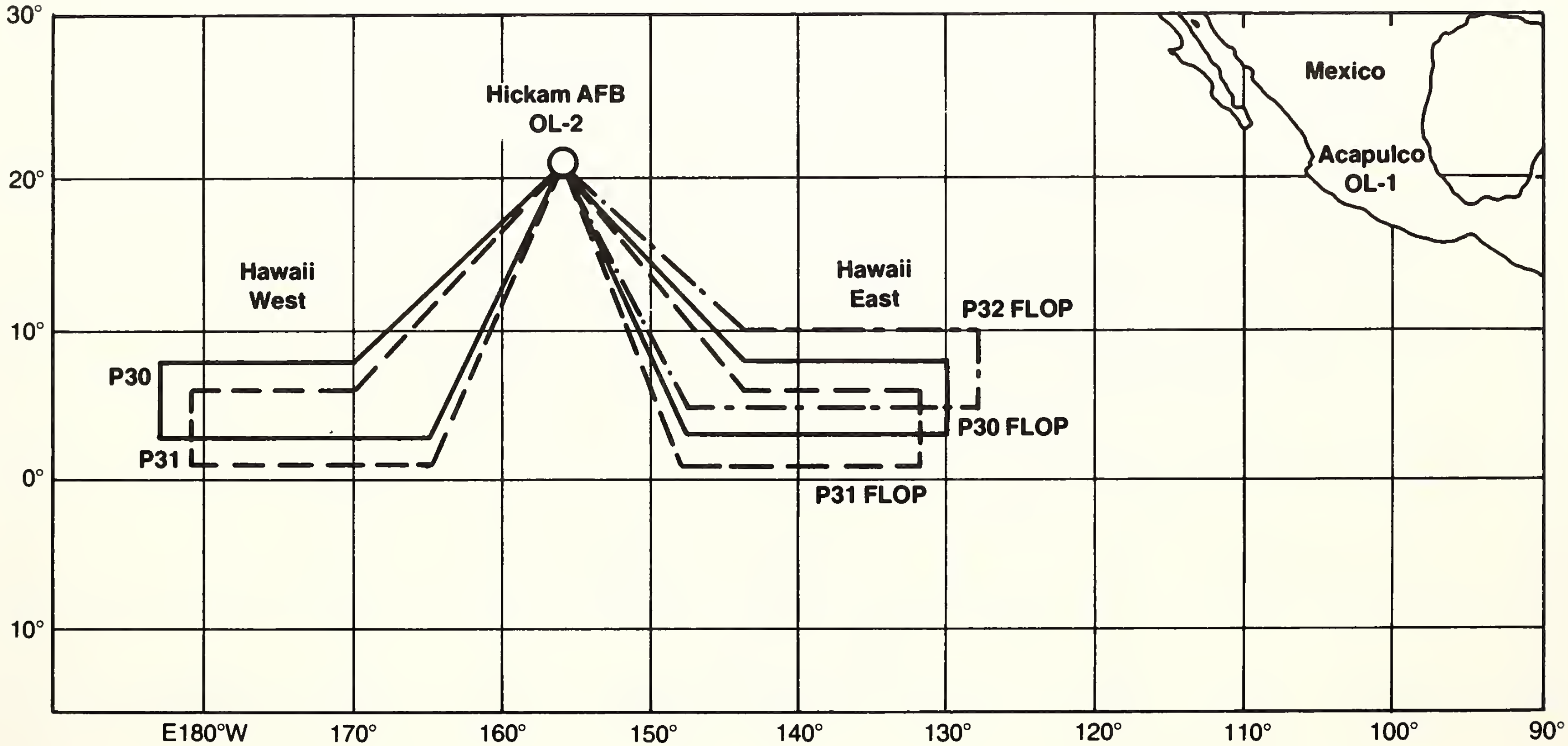

Figure 3.--Dropwindsonde flight tracks for FGGE SOP-I - Central Pacific.

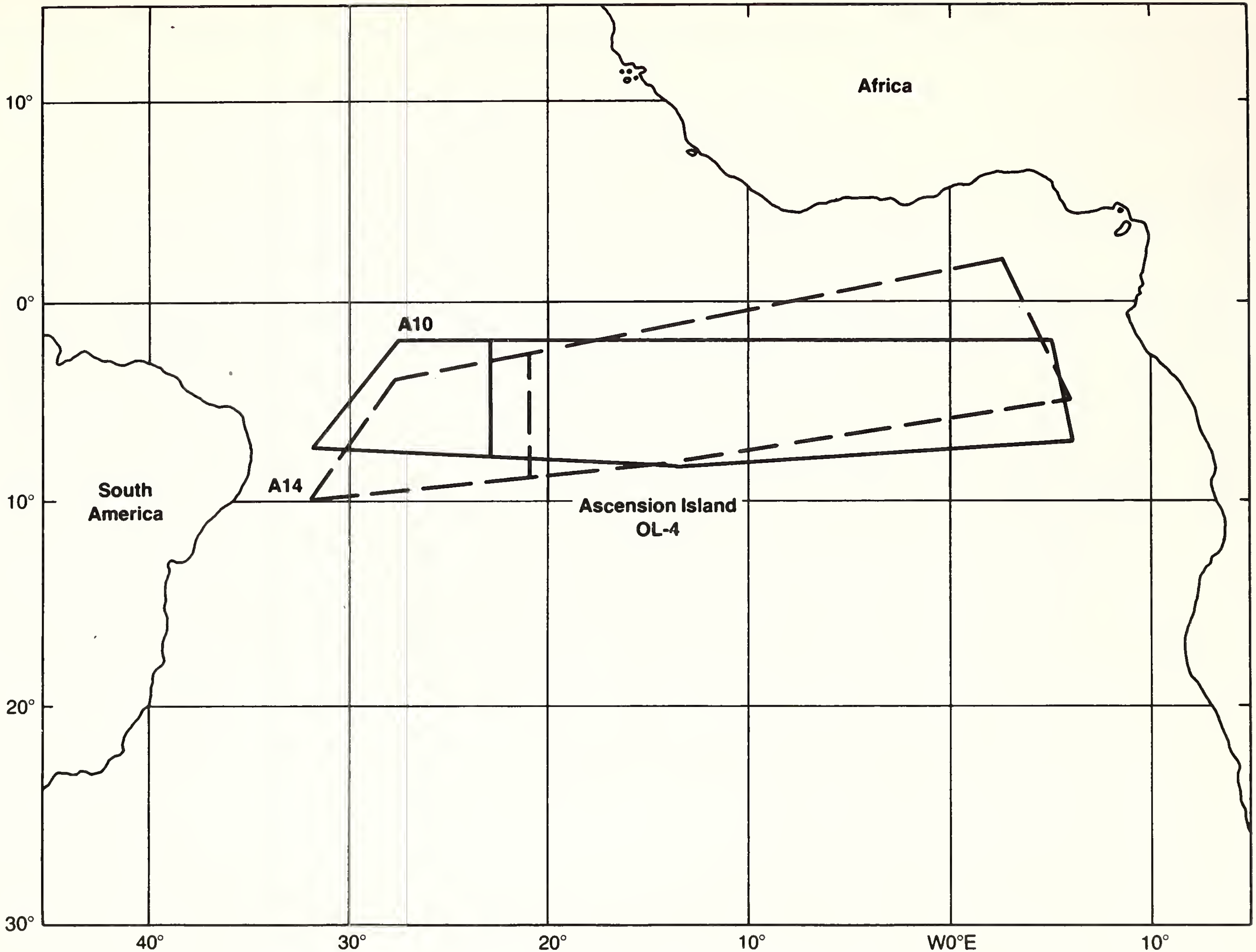

Figure 4.--Dropwindsonde flight tracks for FGGE SOP-I - Atlantic.

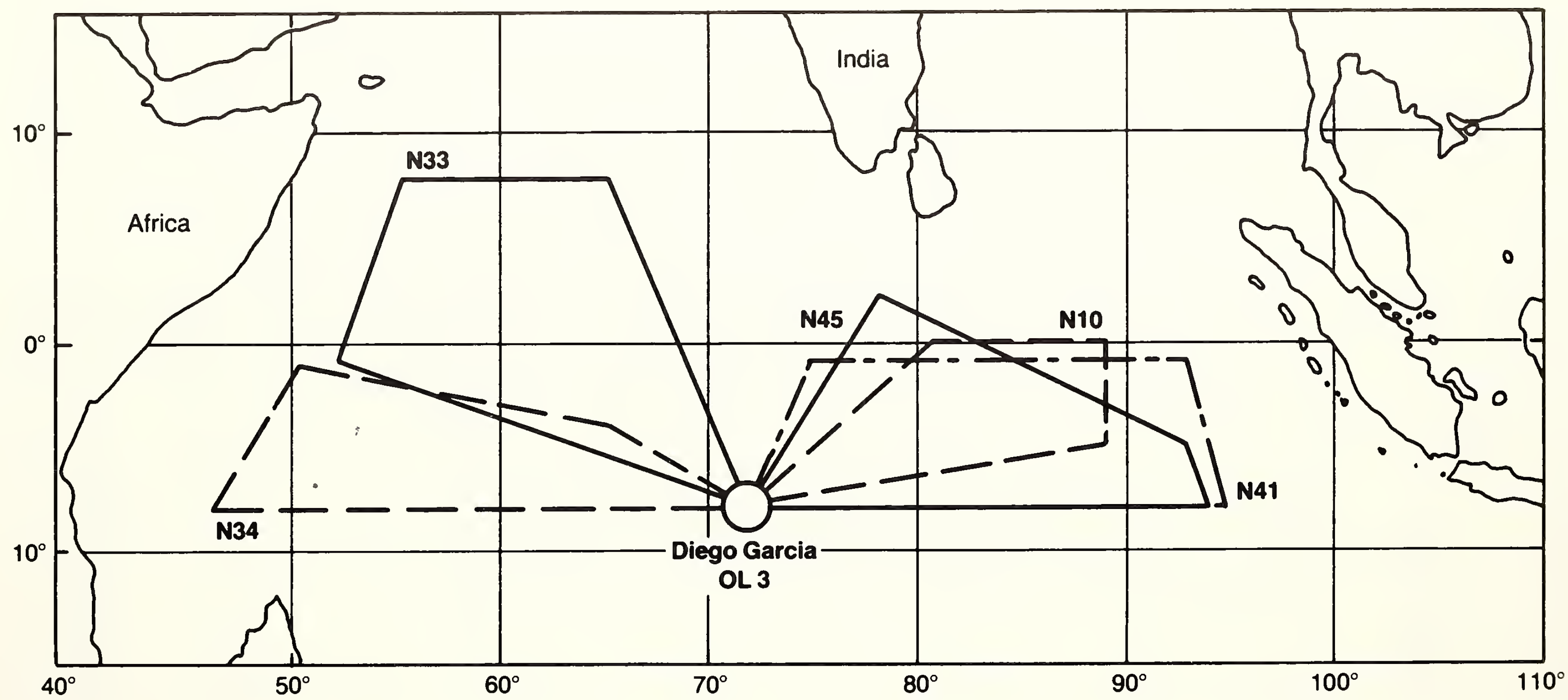

Figure 5.--Dropwindsonde flight tracks for FGGE SOP-I - Indian Ocean.

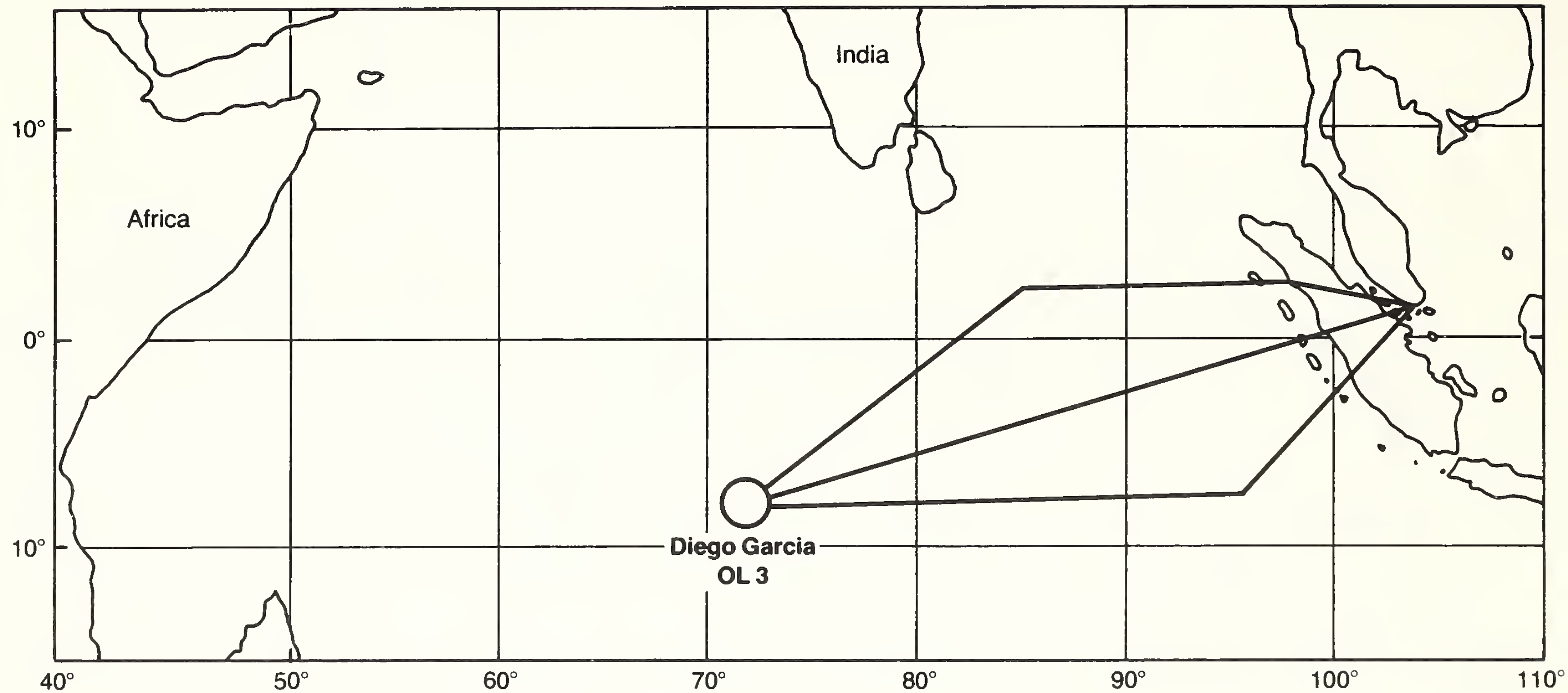

Figure 6.--Dropwindsonde flight tracks for FGGE SOP-I - Indian Ocean - Special flights to Singapore.

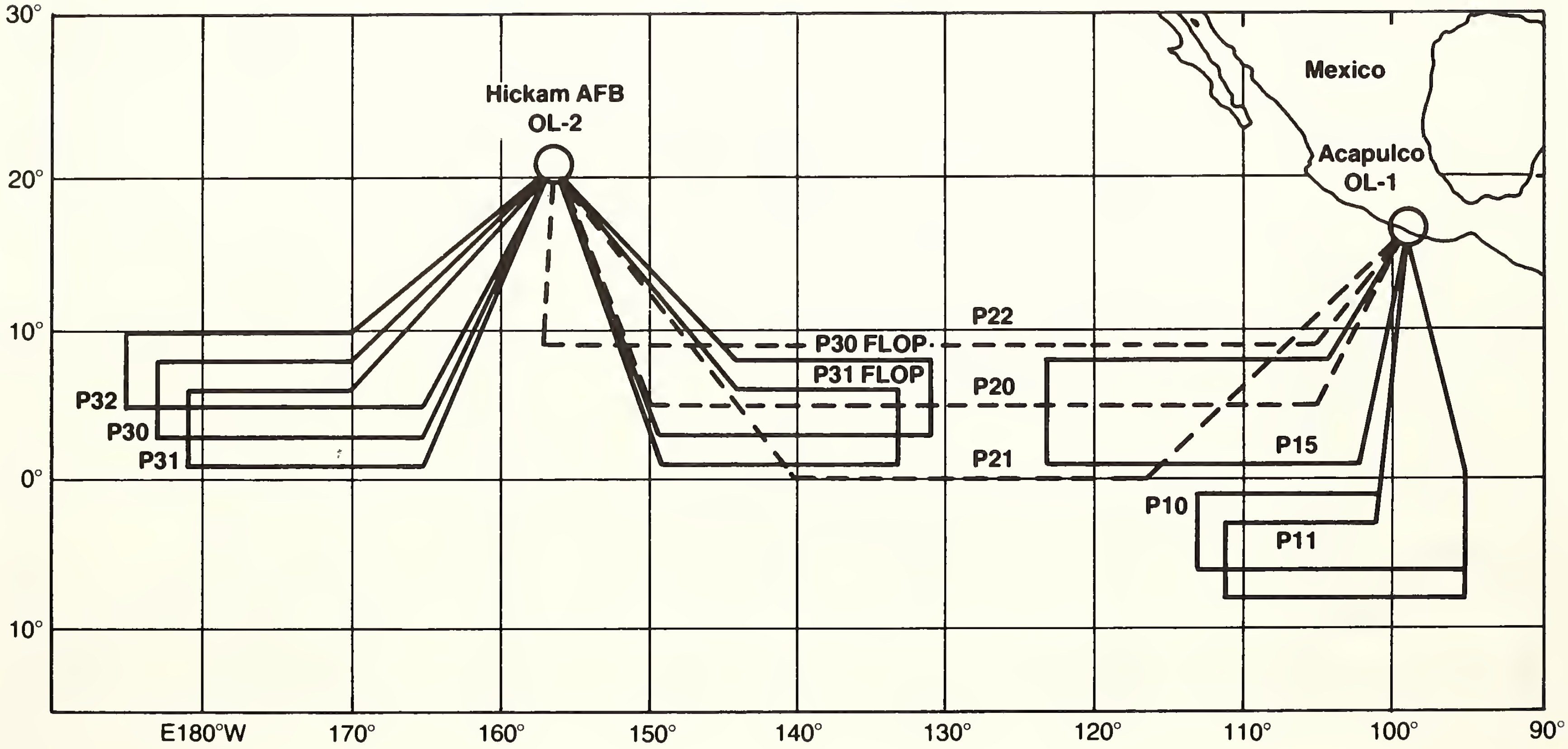

Figure 7.--ADWP Hawaii/Acapulco shuttle and round robin "P" (Pacific Ocean) flight tracks.

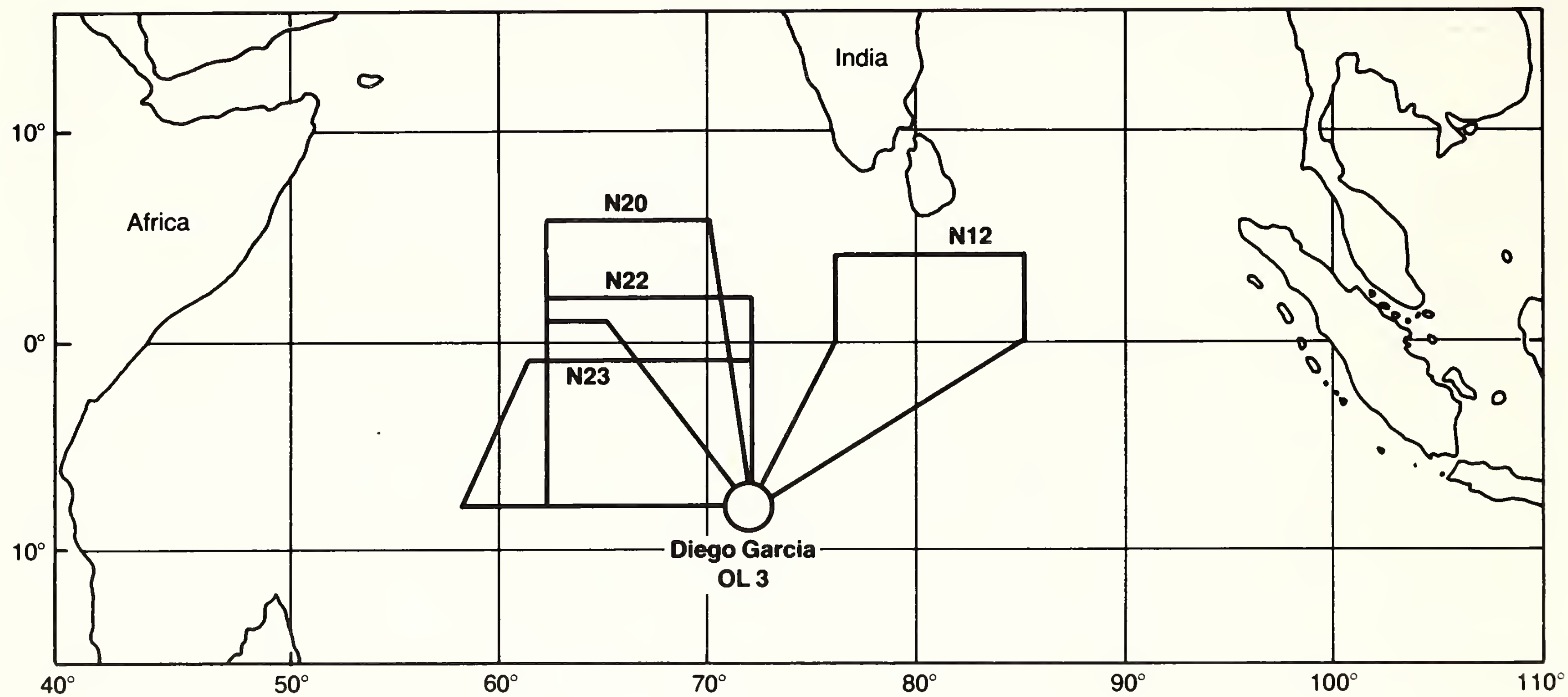

Figure 8.--ADWP Diego Gardia round robin "N" (Indian Ocean) C-130 flight tracks.

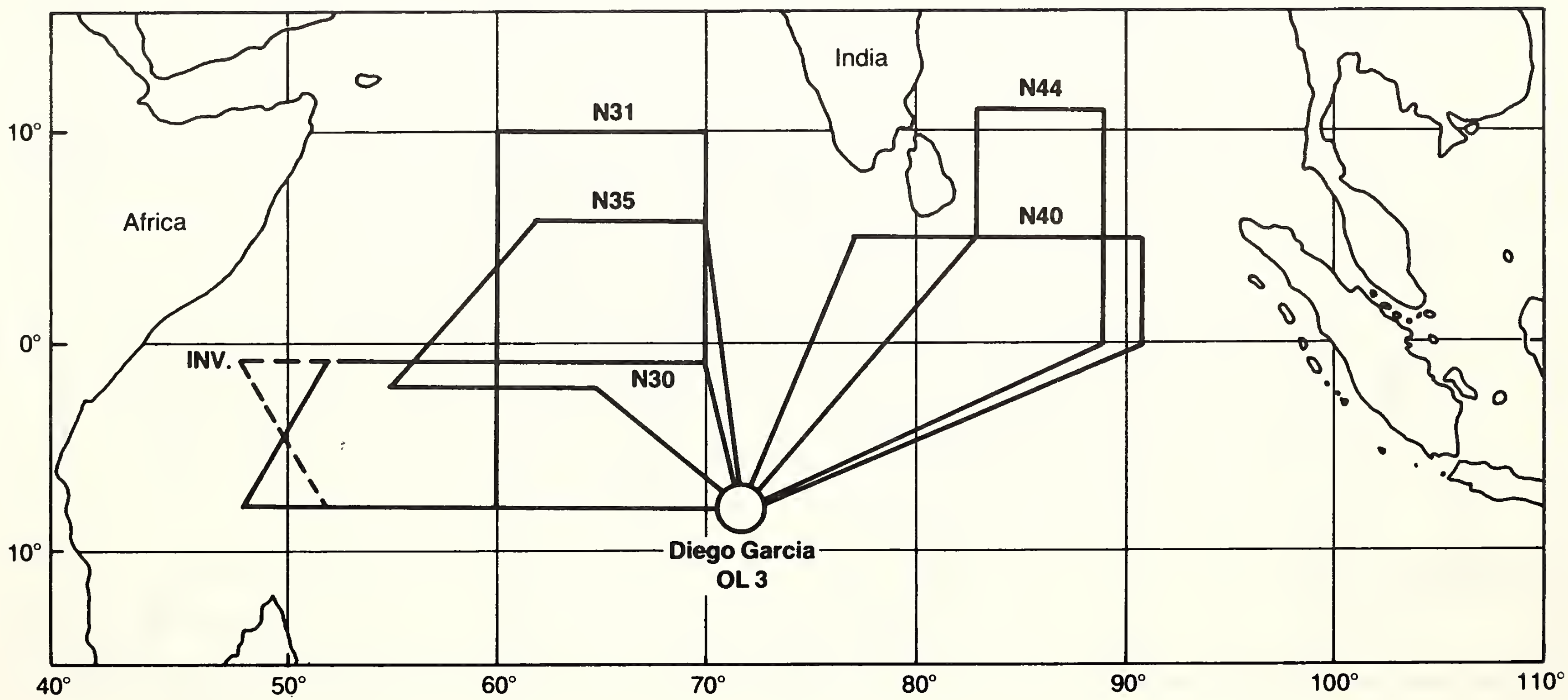

Figure 9.--ADWP Diego Garcia round robin "N" (Indian Ocean) P-3 flight tracks.

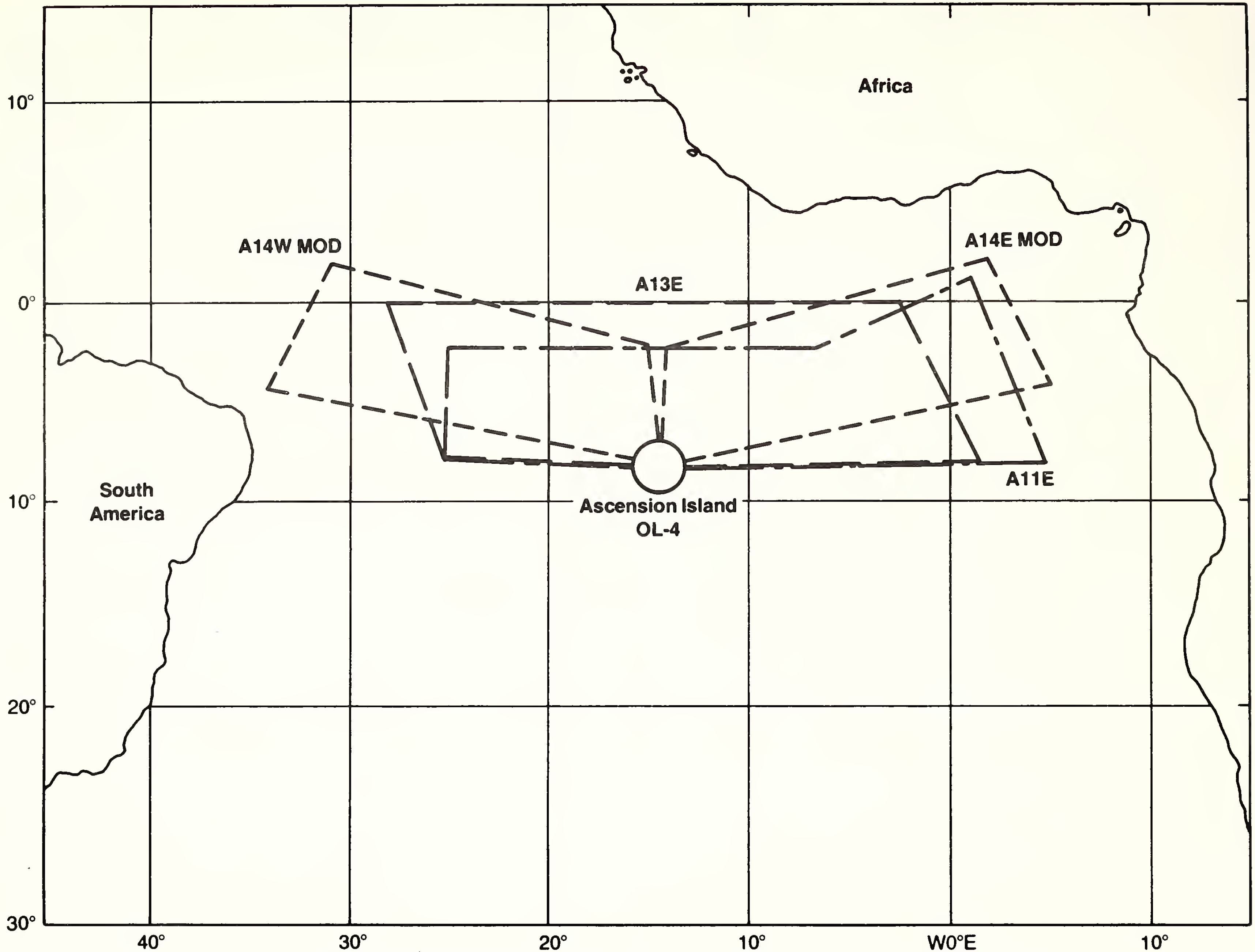

Figure 10.--ADWP Ascension Island round robin "A" (Atlantic Ocean) flight tracks.

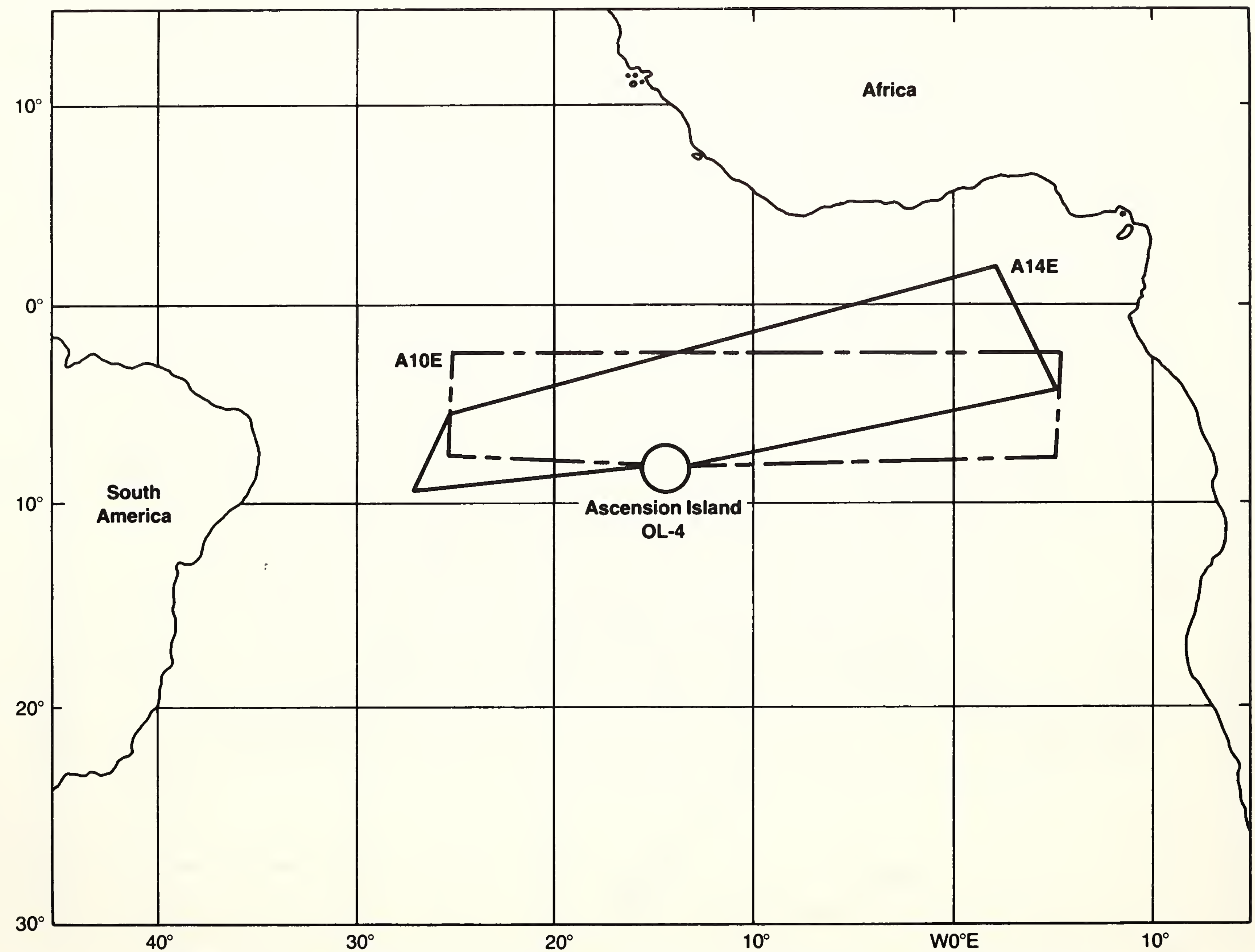

Figure 11.--ADWP Ascension Island round robin "A" (Atlantic Ocean) flight tracks.

CHAPTER 8

TROPICAL WIND OBSERVING SHIPS

By
W. H. Keenan
(U.S. FGGE Project Office)

1. INTRODUCTION

The availability of detailed wind profile data, especially in the tropics, was considered crucial to meeting the scientific objectives of the Global Weather Experiment (FGGE). Expansion and updating of existing equipment provided an increase in wind profile data at land stations. The difficult problem was to acquire data over the large ocean areas. The Aircraft Dropwindsonde Program and the Tropical Wind Observing Ships (TWOS) program were implemented to supplement the land-based wind profiles and to provide the wind data over the oceans. This paper deals with the TWOS program.

A system called NAVAID, based upon the retransmission of worldwide Omega signals (as was the companion dropwindsonde equipment), was developed and purchased for the TWOS ships through a WMO/U.S. coordinated and internationally funded program. This report summarizes: the observations provided by the system, the system description, the results obtained, and development problems and their solutions. Recommendations for evolution of the design for future systems are also included.

2. OBSERVATIONS PROVIDED BY THE NAVAID SYSTEM

The FGGE NAVAID System is an integrated array of electronic and mechanical equipment that measures certain upper air thermodynamic parameters (temperature, humidity, barometric pressure) and utilizes the worldwide Omega Navigation System to determine wind speed and direction. The system has two major subsystems: (a) an expendable balloon-borne radiosonde launched from a ship, and (b) a deck unit to receive the signals telemetered from the sonde and to preprocess and record the data on magnetic tape. Data are recorded as the sonde rises from sea level to the stratosphere - a period of approximately two hours. During FGGE, the magnetic tapes containing the NAVAID observations were forwarded for processing to a special center established by the Finnish Meteorological Institute.

Following are the design specifications for parameters measured by NAVAID:

- o Pressure ± 1 mb over the range 1040 mb to 5 mb
- o Temperature ± 0.5°C over the range +50°C to -90°C
- o Relative Humidity ± 5% up to first tropopause or 300 mb, whichever is lower
- o Wind ± 2 m/sec in areas of good Omega reception (minimum of 5 vertical layers in the troposphere and 3 in the stratosphere).

3. SYSTEM DEVELOPMENT

The Secretariat of the World Meteorological Organization (WMO), with contributions from the United Nations Environment Program and the governments of Saudi Arabia and the United States, undertook a coordinated procurement of the NAVAID system in March 1976 when appropriate industries around the world were invited to respond to a WMO technical solicitation. Industry proposals for

systems were analyzed and evaluated by an "international expert group" convened by the WMO in Geneva, Switzerland. This group selected VAISALA OY of Helsinki, Finland, as the major system contractor, with Tracor, Inc., of Austin, Texas, as the primary subcontractor to VAISALA.

The procurement plan for the NAVAID system was designed to meet two objectives. The first objective was to equip 28 ships with NAVAID deck hardware, defined as modules A, C, D, and E. The modules were defined as follows:

- Module A. This is the data acquisition subsystem. It is composed of the receiving antenna and preamplifiers, an operator control panel, a sonde telemetry receiver, a microprocessor, and dual recording electronics for placing semi-processed data on digital magnetic tape cassettes for subsequent processing at a central location.

- Module C. This contains shipboard support equipment, including a power supply for Module A, a radiosonde balloon launcher, a helium gas flowmeter, and an air conditioner for Module D.

- Module D. This is the shipboard equipment shelter. It is a "knocked-down" prefabricated shelter for housing Modules A and C. This module was designed for ship deck mounting and engineered to withstand the anticipated marine environment of the Global Weather Experiment.

- Module E. Module E contains ancillary equipment (spare parts, tools, expendable supplies) necessary for the operator to maintain and operate the system at sea during the experiment.

The second objective was to acquire a number of Modules B, the NAVAID data processing subsystem. This module, intended for use after the experiment, could be combined with the other NAVAID modules used in the experiment to form a "stand-alone" system which could be used to obtain meteorological soundings and to process the received signals, producing standard coded data on site.

To meet these objectives, the procurement was divided into three phases:

Phase I (February-October 1977)

- Design, build, and test prototype NAVAID units A, C, D, and E.

Phase II (March-November 1977)

- Design, build, and test a prototype Module B processing unit.

- Identifiy spare parts

- Test Modules A, C, D, and E at sea

- Retrofit tested Modules A, C, D, and E and mate them to Module B

Phase III (February 1978-June 1979)

- o Manufacture a number of Modules A, C, D, and E for the experiment, and a number of processing units (Module B) for post-experiment use
- o Train sounding operators
- o Install NAVAID equipment aboard ship
- o Develop the capability to maintain the equipment during the experiment.

4. NAVAID WINDFINDING METHOD

The NAVAID sounding system made use of transmissions from the international Omega navigation network (Figure 1) to determine winds. The pattern of radio waves transmitted by two Omega stations is illustrated by the concentric rings in Figure 2. The hyperbolas in the figure represent curves on which the phase difference between these two transmissions is constant. A set of hyperbolas remains stationary geographically and thus can be considered as a set of coordinates for geographic location.

In order to define a location in this new coordinate system, another set of hyperbolas is required. This is achieved by reference to a third Omega station, as shown in Figure 3. Transmitter pair AB generates one set of hyperbolic coordinates, pair AC the other set. The resulting coordinate grid is seen in the center portion of the figure. These phase measurements from two pairs of Omega stations allow the determination of the exact position of each point on a horizontal plane.

The ascending NAVAID radiosonde receives and relays the Omega signals to the ship -- or (for later use) to the land-based observatory -- where the phases of the Omega signals are recorded for calculating the location of the sonde during its ascent. The successive positions of the sonde reveal the winds. The height of the radiosonde is computed from the three measured thermodynamic parameters.

5. SYSTEM DESIGN

Figure 4 is a block diagram of the NAVAID Sounding System. The radiosonde, which after preparation was attached to a balloon (Totex 650 g) and launched, was a VAISALA type RS2-1 with specially treated and selected meteorological sensors. The sonde received all 13.6kHz signals from the worldwide Omega network and generated signals from its own temperature, humidity, and pressure sensors. Both the Omega and the thermodynamic data were transmitted to the ship via a specially designed, circular-polarized sonde antenna manufactured by Synergetics International, Inc., Boulder, Colorado (403 MHz signal). The composite signal was received aboard ship with a high-performance receiving antenna, also manufactured by Synergetics. The antenna design was selected for optimum performance in the anticipated wind conditions (high elevation angles

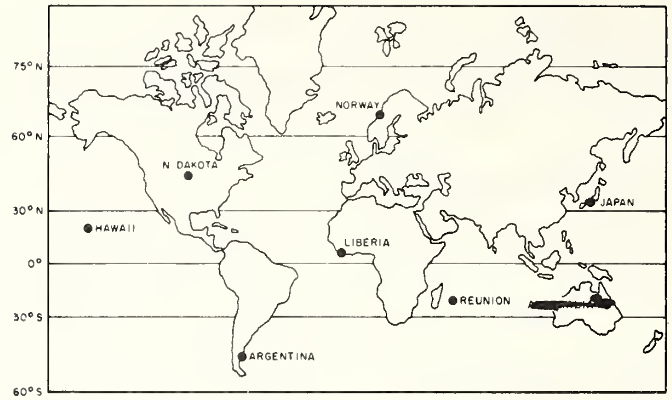

Figure 1.--International Omega network.

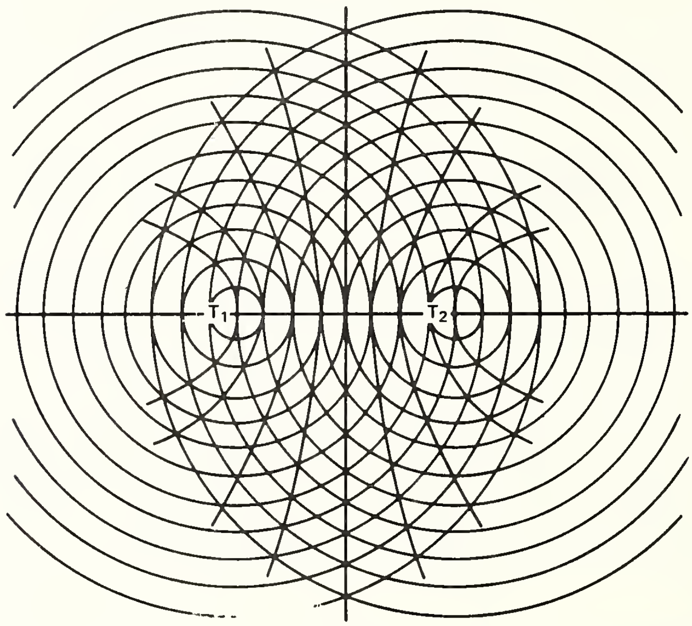

Figure 2.--Hyperbolic curves generated by a station pair.

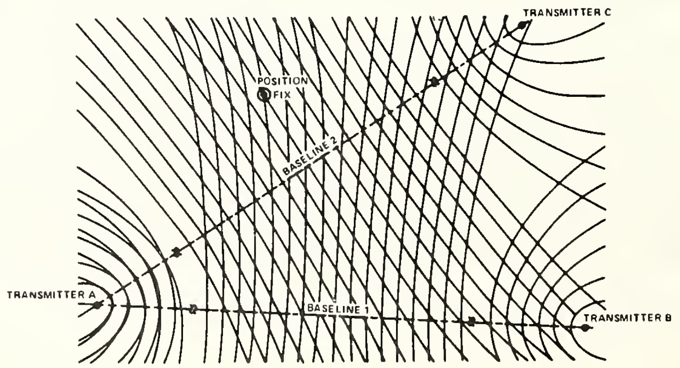

Figure 3.--Hyperbolic grid generated by three stations.

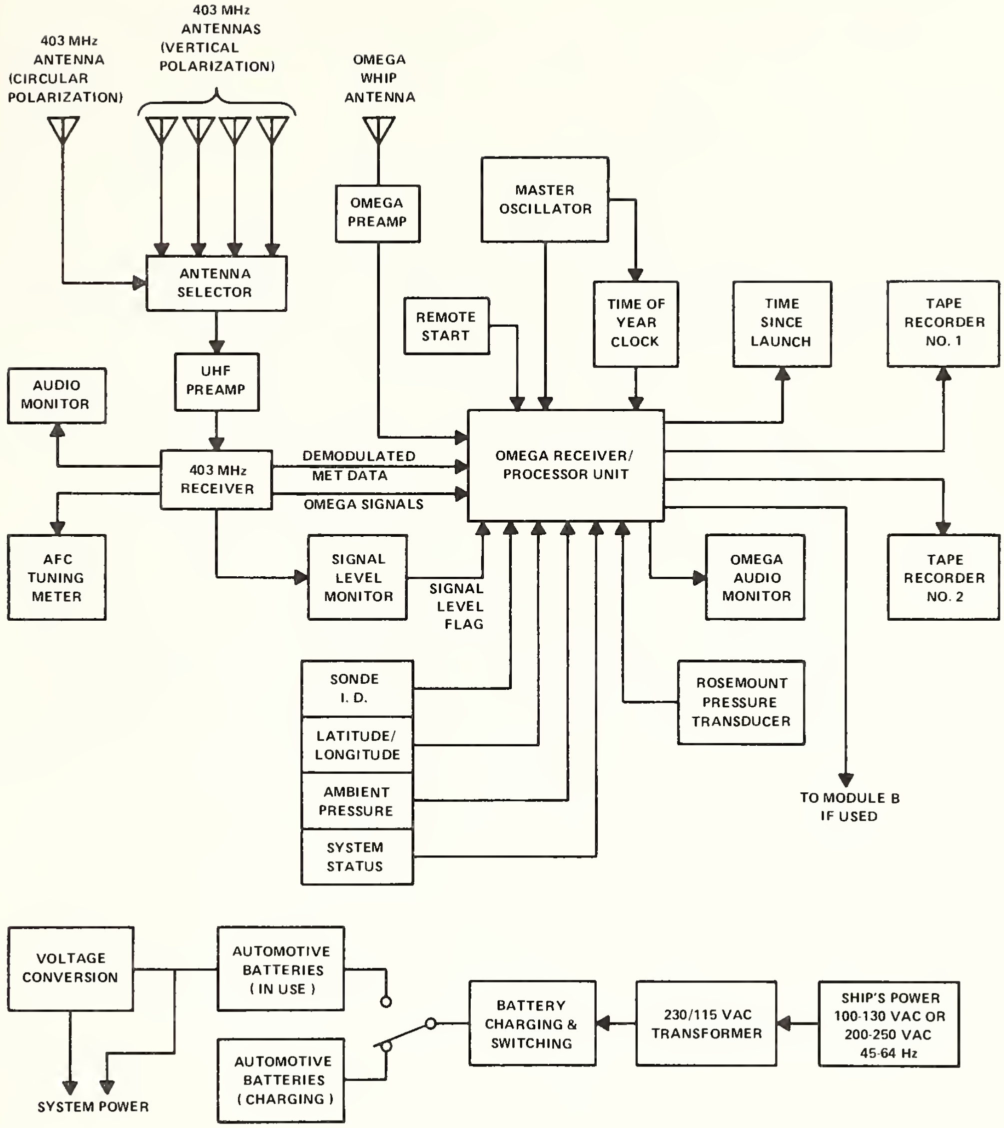

Figure 4.--NAVAID sounding system block diagram.

for the sonde) in the tropics during the experiment. The antenna system was lightweight and small (1.5 kg and 1 m tall) and was quickly clamped to the ship's superstructure.

After reception, the data signal was amplified by low-noise preamplifiers adjacent to the antenna. The signals were then routed to the Module A electronics via prefabricated vapor-block-type cables. The cables were built for external service and were quickly attached to external ship structures. The signal cables entered Module D and were routed to the Module A electronics. The first element in the electronics was the telemetry receiver. The receiver had a signal-level monitor meter which displayed the received telemetry signal strength. This enabled the operator to tune the receiver to obtain the maximum sonde signal. The telemetry receiver had two demodulated outputs. One output contained the sonde thermodynamic data (pressure, temperature, humidity) in the form of square-wave signals within the frequency range of 46 to 52 kHz. The second output contained the 13.6-kHz Omega signals retransmitted from the radiosonde. In addition to Omega signals received from the radiosonde, local Omega signals were received aboard the ship via a standard Omega ship antenna. These signals also were amplified and recorded by the Module A electronics. Local Omega signals were subsequently used in data processing.

Omega signals from the telemetry receiver were routed to the NAVAID receiver processor unit (RPU). This receiver contained a microprocessor which was the heart of the electronics aboard ship. The program for the processor was stored in ROM (read-only memory) and organized in a modular form. Omega signals from the telemetry receiver entered the RPU and were synchronized automatically to the Omega transmission format. In addition, the RPU performed amplification, filtration, noise suppression, signal compression, phasing, and digitization of the sonde's Omega signal, which was comprised of the signals from all Omega stations within receiving range of the sonde.

Meteorological (thermodynamic) signals from the telemetry receiver were also routed to the RPU for digitizing and formatting. The RPU compares frequency samples to establish and maintain synchronization with the sonde. In addition, the RPU filters and averages the meteorological data. The Omega and meteorological data were separately buffered in the RPU data memory. Whenever either buffer was filled with data (every 10 seconds for the Omega data and 6 seconds for the meteorological data), the buffers were read out to the Module A recorders. For data security, the NAVAID system recorded data in parallel on two Memodyne recorders using certified data-tape cassettes.

6. OPERATOR CONTROLS AND DISPLAYS

Figure 5 depicts the NAVAID operator's control and display panel, part of Module A. The panel cues the operator through a launch sequence with the use of colored indicator lights. In addition, the panel provides thumbwheel switches which enabled the operator to enter meteorological surface data as well as an error-correcting sonde identification code. Specific sonde identification provided the postprocessing center (the TWOS NAVAID Data Center of the Finnish Meteorological Institute, Helsinki, Finland) with the capability of reducing sonde bias errors.

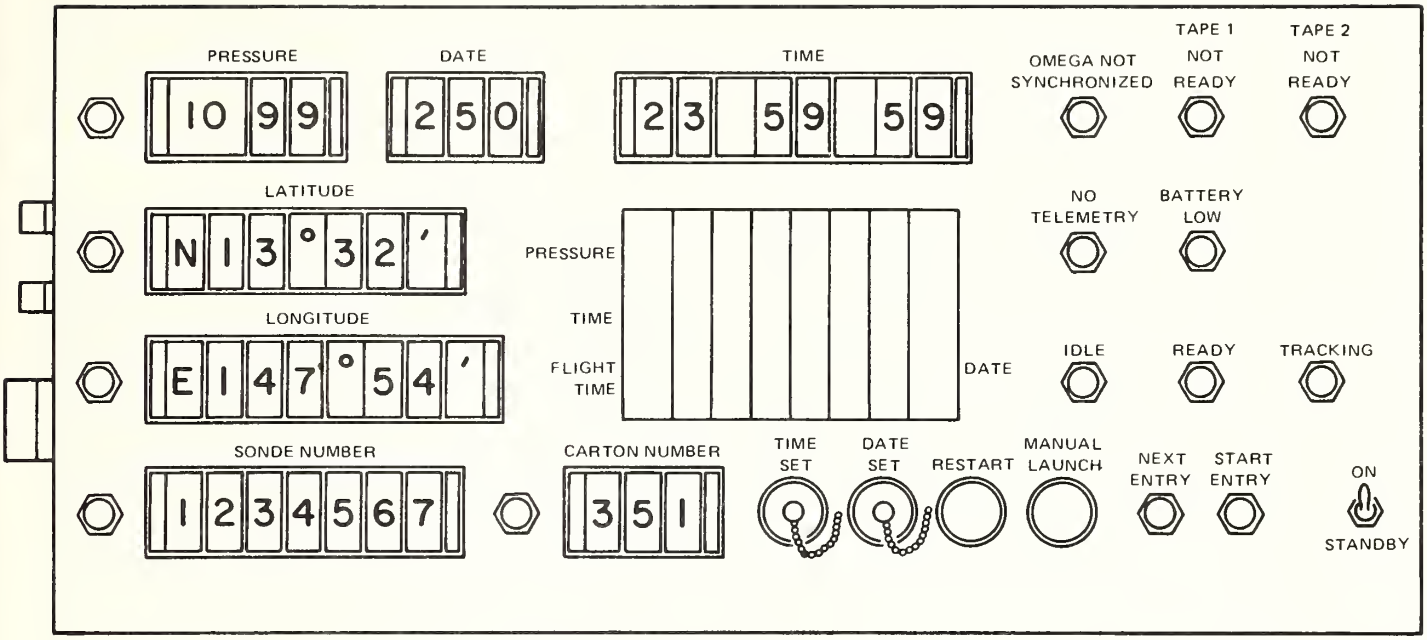

Figure 5.--Operator control data entry and display panel.

The NAVAID Sounding System had the ability to measure and record surface (shipboard) atmospheric pressure automatically. This was accomplished with a Rosemount pressure transducer. This measurement was made as a backup to the operator-entered pressure measurement, which was obtained from an aneroid barometer provided with the system and mounted within Module D. At the time of the radiosonde launch, the Module A electronics were activated and the recorders began to record when a "launch signal" was received from the radiosonde launcher located on deck. The launch signal was obtained from a "nail plate" switch attached to the sonde and routed to the RPU by a weatherproof signal cable.

6.1 Modules C, D, and E

6.1.1 Module C

The components of Module C were the following:

- Power System. The power source for the NAVAID consisted of two banks of sealed lead-acid storage batteries, each containing two batteries. One of the battery banks supplied power for operation of all the electronics. During this time, the other bank was being charged. The charger, then, was the only device that needed to interface directly with the ship's power system. As such, it was designed to operate over a wide range of power frequencies and voltages. Also, because no electronics were connected to the charger, power-line noise and voltage or frequency fluctuations did not affect the system's operation. Battery capacity was such that the system would operate for roughly three launches before it needed recharging.

- Air conditioner. This operated directly from the ship's service power; it too operated on a wide range of ships' voltages and frequencies.

- Balloon inflation and release device. This was a new design for NAVAID. The device was a portable aluminum-framed canopy. Release of the balloon from the canopy was accomplished by a single-handed pull. The sonde, after being prepared for launch, was held in a special container attached to the release device. The sonde was held firmly in place in the container with a "nail plate" attachment. As the sonde was pulled away from the launcher, the nail plate rose a short distance with the sonde, triggering a balloon release switch which activated the start of the Module A recording system.

- Helium inflation gas regulator and flowmeter. During inflation of the balloon, the precise helium gas flow was monitored. When a prescribed amount of gas had been delivered to the balloon, an audible alarm and a flashing light were activated.

6.1.2 Module D

The NAVAID Sounding System was installed on a great variety of ships for the Global Weather Experiment. Many of the ships were not specially outfitted for environmental research. Consequently, the system was adaptable and

easily installed. The shelter, Module D, facilitated this. Figure 6 is a cutaway sketch showing the organization of the interior.

The module was manufactured with a foam-core sandwich construction for high strength and low weight. It was shipped in a "knocked-down" configuration and erected in approximately 2.5 hours with a minimum of tools. The total weight of the module, including the power and air conditioning systems, was approximately 300 kg. The unit had adjustable legs for leveling on a canted ship's deck and was constructed from materials able to withstand the anticipated marine environment. Within the module all the electronics were supported by shock-isolating equipment which reduced the shock and vibration transmitted to the module while the ship was under way.

6.1.3 Module E

Module E contained the ancillary equipment necessary for the operator to maintain and operate the system at sea during the Global Weather Experiment. Many of the ships were at extended distances from their home bases and were on station for as long as 35 days. The design concept for the maintenance at sea program was to avoid having the operator repair anything within the electronic chassis. It was felt that the levels of training, test equipment, and spare parts required to repair the equipment at sea would necessitate an unacceptably large amount of training for the operator and place the system costs substantially over budget. System reliability was created with the use of highly reliable components, independent processing, and substantial burn-in time for the units prior to shipment. Therefore, Module E contains only those items which a reasonably skilled operator would replace at sea with a minimum of support equipment.

7. TESTING AND RESULTS

The testing of the NAVAID was carried out during the period 15 November 1977 through 13 January 1978, when 34 soundings with both Module A and Module B were performed in Helsinki under the supervision of the Finnish Meteorological Institute. In six of these soundings the Helsinki airport radar (Selenia Meteor 200 M RMT-2S) was used as reference. The comparison between the various systems gave very satisfactory results as shown below, where winds determined by the Finnish Meteorological Institute from Module A recordings, winds computed in real-time by Module B, and radar winds (using in all cases a four-minute smoothing scheme) are compared for six test soundings. The RMS differences are of the same order as the windfinding accuracy of the reference radar.

TABLE 1.--Root-mean-square differences in wind direction (dd, degrees) and wind speed (ff, m/s) for Module A / Radar and Module B / Radar based on six pairs of test soundings.

MODULE A / RADAR		MODULE B / RADAR	
dd(°)	ff(m/s)	dd(°)	ff(m/s)
1.45	0.89	1.84	1.01

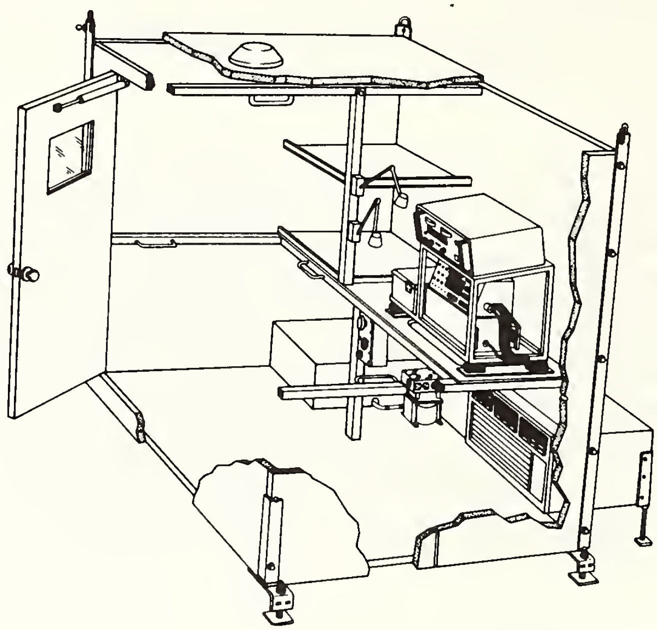

Figure 6.--NAVAID module D cutaway.

8. NAVAID WIND DATA QUALITY DURING FGGE

The most important atmospheric feature to be defined by the NAVAID is the vertical wind profile. Assessing the NAVAID wind accuracy is not straightforward, because it varies with time and geographical location of the sounding, is dependent on the software used for the Omega data reduction, and is directly related to the quality of the Omega signals available. However, by monitoring the behavior of the signals one can estimate the accuracy of the wind profile. In the data processing it is possible to vary the signal integration time so that a desired wind accuracy will be achieved. If the quality of Omega signals is good, an integration time of one minute is enough to provide accuracy of, say, 2 m/s. In poorer Omega conditions, it would be necessary to increase the integration time to attain the same accuracy. Each selected integration time corresponds of course to a certain vertical layer through which the balloon ascends during the integration time. There is thus the opportunity for a trade-off between accuracy and vertical resolution.

Table 2 below, which was prepared at the TWOS NAVAID Data Center in Helsinski, shows the combined statistics of the NAVAID wind accuracy and the corresponding vertical resolution for all NAVAID ships during the two FGGE Special Observing Periods. From the table it can be concluded

Table 2.--Root-mean square wind vector error for various vertical integration layers according to Lange [1]

	Estimated RMS-error of vector wind less than (mps)									Total number of soundings
Vertical interval less than (m)	0.5	1.6	3.3	5.5	8.1	11.1	14.5	18.3	22.4	
100			1							1
330	17	68	1							86
670	162	530	5							697
1100	234	1641	21	1						1897
1620	65	526	7							598
2227	22	184	4							210
2909	8	51	1							60
3666	1	17	5	3		1				27
4495		2	1						3	6
Total number of soundings	509	3019	46	4		1			3	3582

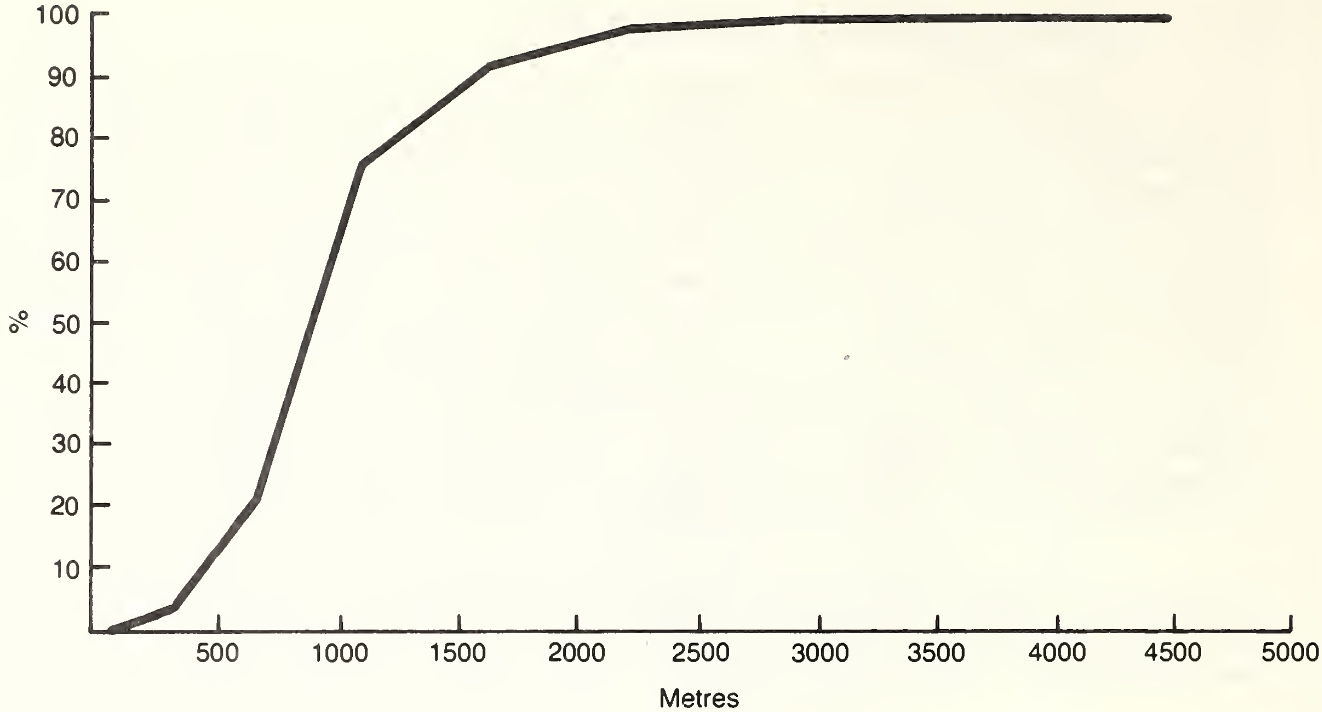

Figure 7.--Frequency distribution of vertical integration layer for NAVAID data given in form of percentage of soundings having integration thickness less than the value indicated on the abscissa.

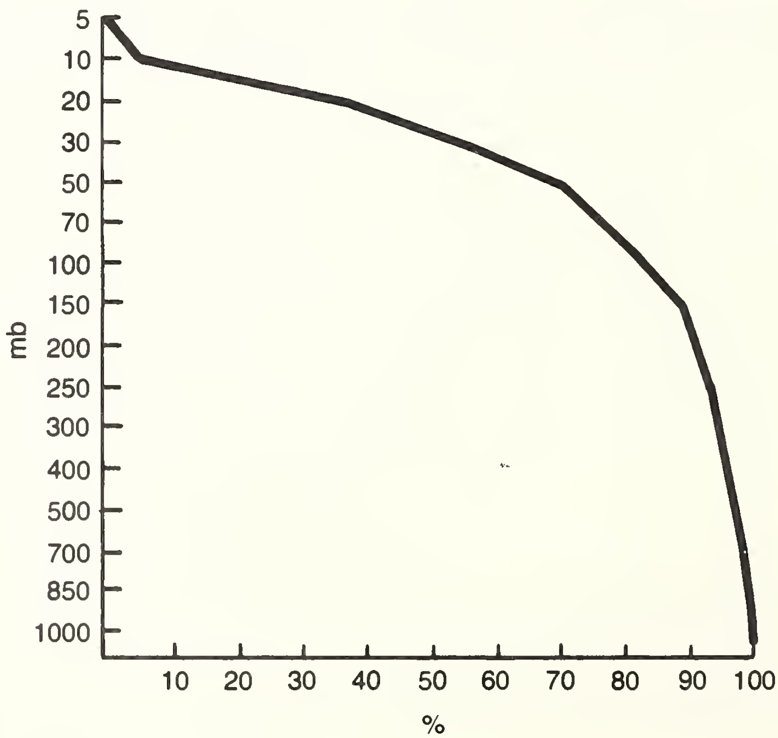

Figure 8.--Frequency distribution of the pressure altitudes attained in the form of the percentage of soundings exceeding given pressure altitudes.

that 98.5% of the soundings had RMS-error of vector wind less than 1.6 m/s disregarding the integration interval. The frequency distribution of the integration thickness for the data having wind accuracy better than 1.6 m/s is given in Figure 7 which shows that in three quarters of the soundings the integration interval was 1100 metres or less. In 90% of the cases the integration interval was less than 1600 metres. Please note that in the shipboard NAVAID system, the relation between time and layer thickness is approximately linear (1 minute equals about 300 meters). In contrast, the parachute-borne dropwindsonde shows a more linear relationship between time and pressure difference (1 minute equals about 25 millibars).

Figure 8 shows the frequency distribution of the pressure-altitudes attained in the form of the percentage of soundings exceeding given pressure altitudes. About 90% of the soundings reached 150 mb or higher whilst two thirds penetrated beyond the 50-mb level.

9. PERFORMANCE OF U.S. TWOS

During FGGE, nine U.S. ships were equipped with NAVAID. Of these nine ships, six were operational during each SOP. During the first SOP, systems were installed on the RESEARCHER, DISCOVERER, GYRE, TOWNSEND CROMWELL, DAVID STARR JORDAN, and the WILKES. The DISCOVERER, after 19 days of successful operation during January, experienced a failure in the NAVAID system electronics. As a result, they were unable to make soundings in February. The WILKES experienced battery problems early in the first SOP and was able to make only one sounding per day in January and after five days of operation in February, the system failed completely. The RESEARCHER and GYRE were able to maintain their sounding schedule; however, some soundings failed to reach minimum altitude due to problems with the balloon inflation system.

The following NAVAID system shifts were made for the second SOP:

FROM	TO
DISCOVERER	OCEANOGRAPHER
DAVID STARR JORDAN	COLUMBUS ISELIN
TOWNSEND CROMWELL	KNORR

No major NAVAID system failures occurred during the second SOP; however, some observations were lost due to changes in ship schedule and operational requirements.

The Operations Plan for U.S. TWOS scheduled approximately 370 total at-sea ship days between 10°N and 10°S latitude. Hence, at a rate of two soundings per day per ship, approximately 740 soundings should have been made. As shown in Table 3, U.S. ships made a total for both periods of 653 soundings or almost 90% of the planned total number. The DISCOVERER and WILKES had problems with their NAVAID systems, while the GYRE and OCEANOGRAPHER had problems maintaining their schedule.

The following table summarizes the NAVAID soundings taken by U.S. ships during FGGE.

Table 3.--Soundings made by U.S. TWOS

	SHIP	LOCATION (OCEAN)		SOUNDINGS COMPLETED (INCLUDING SUCCESSFULLY PROCESSED DATA)
SOP I				
	WILKES	Indian		22
	RESEARCHER	Atlantic		55
	JORDAN	Pacific		71
	CROMWELL	Pacific		89
	GYRE	Pacific		31
	DISCOVERER	Pacific		18
			TOTAL	367
SOP II				
	RESEARCHER	Indian		69
	COLUMBUS ISELIN	Indian		50
	KNORR	Pacific		26
	OCEANOGRAPHER	Pacific		120
	GYRE	Pacific		79
	WILKES	Indian		23
			TOTAL	286

While U.S. ships did not accomplish 100% of their planned soundings, they did provide approximately 1/5 of the total soundings (3,582) made by all ships equipped with the WMO FGGE NAVAID systems.

10. LOGISTICS

NAVAID, in order to operate successfully, had to be installed on research ships all over the world. This installation was compressed into a three-month time frame prior to the start of SOP-1 because of equipment manufacturing lead times and research ship availability for installation. It was felt at the beginning of the program that both the logistics effort (shipping, scheduling, clearing through customs, etc.) and the installation effort would be the most difficult part of the program and be fraught with unforeseen problems.

The concepts for logistics were reasonably simple and straightforward. The following are the highlights of the plan:

- A detailed plan for logistics was developed which pinpointed installation ports, ship schedules, and installation dates.
- All NAVAID equipment was to be shipped on a worldwide basis by a single shipping agent. The agent was selected by competitive procurement against a specification of performance and price.
- All NAVAID equipment would be installed by an experienced, well rehearsed installation team(s). The teams would be flexible, totally familiar with shipping and customs requirements, multilingual, and have total responsibility for the installations when in the field.
- A central coordinating center would be set up at WMO Headquarters in Geneva, Switzerland. This center would be aware of up-to-the-minute changes in any program requirement, shipping schedule, or ship availability and be able to quickly communicate with the installation teams or vice versa on a 24-hour-per-day, 7-day-per-week basis.

Figure 9 is an overview of the NAVAID worldwide installation schedule for SOP-I. It is broken down into geographic teams and specific installation times for each of the NAVAID ships.

NOAA recognized the importance of the logistics effort for the FGGE NAVAID and seconded a logistics specialist to the WMO for the duration of the program. He was involved in the generation of the logistics plan, the selection of the shipping contractor and served as leader on one of the installation teams.

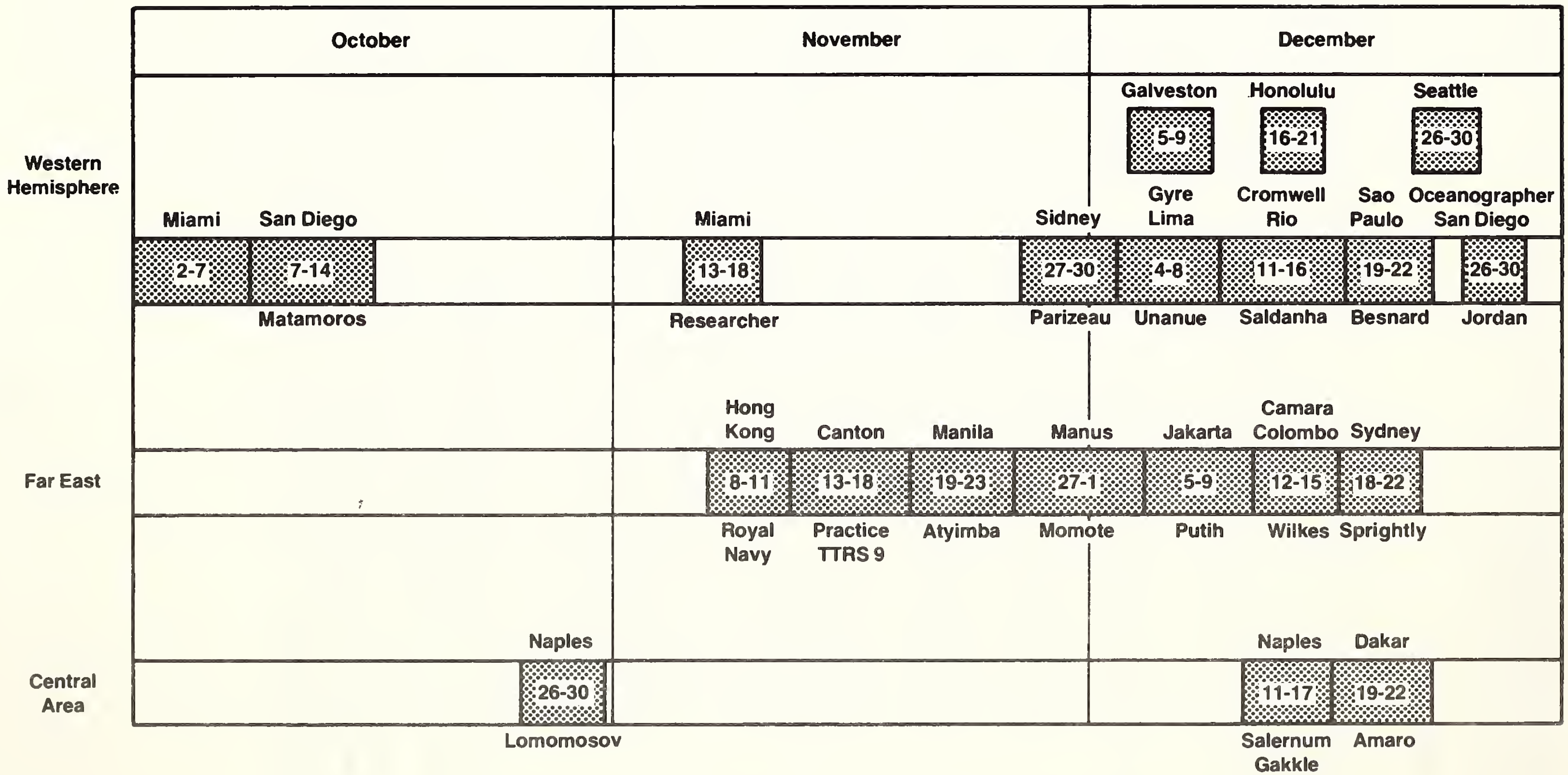

Figure 9.--Installation schedule - NAVAID ships.

In addition NOAA provided additional personnel to other installation teams and supported the overall logistics effort.

A program like NAVAID succeeded logistically only because extremely dedicated people, working with a well-organized plan, make the shipping arrangements, customs formalities, and ship installations happen. The highest praise must be given to the NAVAID contractor VAISALA OY of Helsinki, Finland, and especially to their dedicated field service engineers that worked under extreme conditions to make the installations successfully.

11. PROBLEMS AND SOLUTIONS

After evaluation of the NAVAID data, discussions with the NAVAID operators and evaluation of the ship reports, the following were judged to be the major system problems.

- o Balloon inflation volume difficult to accurately measure with the NAVAID flow meter.
- o Balloon launcher too fragile and balloon tie-off too long and complicated a procedure.
- o It was possible to overcharge system batteries, and with heavy system use, the charging system did not maintain battery charge.
- o Unexplained "jumps" in recorded signal data were observed on some of the signal records.

12. PROPOSED SOLUTIONS

- o Redesign the balloon inflation system based on an automatic volumetric measurement rather than an operator-observed digital flowmeter system.
- o Redesign balloon launcher to be simpler to assemble and made from stronger materials, even with a sacrifice in weight.
- o Redesign battery charging system for higher charge capacity and complete shut-off when the NAVAID system is inactive for long amounts of time.
- o Data jumps appear to be caused by the operator retuning the receiver at too rapid a rate. Additional operator training may be the only reasonable cure for this problem.

13. CONCLUSIONS

The NAVAID system contributed approximately 3500 soundings of the Equatorial Tropical Atmosphere during the FGGE Special Observing Periods. The system performed, for a high percentage of cases, within the design requirements. The system was deployed on a worldwide basis and installed on approximately 30 ships. The delivery and installation dates were accomplished according to the required schedule and total system was produced within budget.

CHAPTER 9

AIRCRAFT TO SATELLITE DATA RELAY (ASDAR)

By

James K. Sparkman, Jr. (NOAA)
James Giraytys (NOAA)
George J. Smidt (NOAA)

1. INTRODUCTION

Wide-bodied jet aircraft were used as data collection platforms for in-flight meteorological reports for research projects, almost from the moment B-747s were introduced as commercial carriers in 1970. Data were collected on board using the airplanes' own sensors for wind and temperature.

For many years, meteorologists had urged the development of a fully automated system for data collection from aircraft in flight. An automatic system would be free of the human errors found in voice-radioed aircraft reports, and of the prohibitive manpower costs for collection at major terminals of hard-copy reports made by aircrews during flights. Initially, a tape system using hardware already installed aboard many aircraft seemed a low-cost approach to an improved operational data collection system. However, removal and carrying of tapes from arriving aircraft to processing centers for transcription proved to have many of the costs and delays experienced in collection of hard-copy reports. The delays proved unacceptable.

As preparations for the First GARP Global Experiment (FGGE) took shape, it became evident to planners that all the elements needed for a worldwide automated data collection system using aircraft were in place. An automated data collection system for aircraft reports was at last possible. Collection system elements included:

(1) Quality sensors for winds and temperature installed aboard aircraft;

(2) Digital processing of sensor-signals aboard aircraft, yielding digital values in engineering units for winds, temperature, altitude, and aircraft location;

(3) Satellites, with a proven capability to relay reports (from ground-located "Data Collection Platforms" (DCPs)) to ground receiving stations;

(4) Established communications between satellite, ground receiving stations, and meteorological data processing centers;

(5) Worldwide circuits for meteorological data, called the Global Telecommunications System, through which aircraft reports can be sent to data users as required.

In January of 1975, NASA and NOAA agreed on a plan to develop ASDAR as a possible operational data system and for an initial test of the system during FGGE. Key events in the ASDAR development are listed chronologically in Table 1 at the end of this chapter.

The goal of the ASDAR program was to develop an electronic package for installation aboard aircraft which simultaneously (a) could collect meteorological reports, formulate them into an appropriate message, and radio the message to relay satellites, and (b) would be acceptable to airlines and air-safety regulatory agencies. There were a number of technological uncertainties

to face to achieve this goal. What the ASDAR program provided for FGGE and some of the difficulties that had to be overcome to meet the above goal are outlined in the sections which follow.

2. PROGRAM DEVELOPMENT

When NASA's Lewis Research Center began to work jointly with NOAA to develop ASDAR, it was clear that data could be collected from aircraft sources and that digital messages from such avionics units as Inertial Navigation Systems (winds and location) and Flight Data Acquisition Units (temperature and altitude) could be selected and re-assembled into suitable messages, and stored until a specified time for transmission to a satellite.

The main area of uncertainty was the radio link between the aircraft and the geostationary relay satellites, located 22,000 miles overhead. Relay satellites are operated by the U.S., Japan, and the European Space Agency. By their overlapping fields of view, they provide virtual global relay coverage up to 80° latitudes. NASA's engineers made a comparison between the needs for an ASDAR radio system, and the hardware used for tiny DCPs to report rainfall rates, river heights, snow depths, and many other environmental parameters. DCPs, they noted, require no more power than a handi-talkie (6 watts), but are given a high-gain narrow beam antenna that points precisely at its relay satellite. Since a five-foot-long helical antenna cannot be mounted on top of a B-747, the challenge for ASDAR was to build a large transmitter to feed a small, flat, low-gain antenna mounted flush atop an aircraft, radiating its signals in all directions upward. The need for aiming antennas would be obviated.

The 80-watt transmitter developed by a NASA contractor for the program, operating at 402 MHz, represented state-of-the-art technology. After three years of deployment, the transmitter has a mean-time-between-failure of six months. This failure rate is still too great for an operational program. However, between failures, the transmitter provides an unusually "clean" signal (free of unwanted harmonics and other off-frequency components) that delivers ASDAR messages to the satellites at appropriate signal levels. Drift of the transmitter frequency has not been brought wholly within suitable bounds, largely because of the uncertainty as to how many hours each day a given ASDAR unit will be provided with power. (Transmitters generally drift—that is, change frequency—to lower frequencies when off power, but to higher frequencies while operating. Current drift rates carried most units out of band within 10 months.)

The ASDAR antenna, while not a new design, was new to its application. The working part of the antenna, a block of plastic with embedded wires, (8 inches square by 1/2 inch thick) was installed into a machined-aluminum "picture frame" milled to fit flush on the cylindrical top of a B-747. Occasional failures (five of seventeen failed in two years) resulted from seepage of water into the plastic, driven by the force of flight-speed winds.

Given the overwhelming success of the satellite DCP program (platforms now number into the thousands), it was not likely that the ASDAR antenna system would totally fail. However, it was considered possible that the ASDAR unit

might operate successfully only when near a satellite's sub-point. Originally, NASA promised data relay only to distances no more than 45° away from beneath the satellite, in any direction.

It is to the credit of the Lewis engineers that they evolved a design which did not overload the satellite (with too strong a signal) when aircraft were just below the satellite, yet provided a sufficiently strong signal to relay messages until aircraft disappeared from sight of the geostationary satellite. Reports from flights to or across the Earth's poles were generally relayed to about 82° North or South.

3. DATA PROVIDED BY ASDAR

The ASDAR system obtains winds from the host aircraft's Inertial Navigation System (INS). In an INS, the calculation of wind values is part of the operation necessary to guide an aircraft on an "automatic pilot" course compensating for cross winds. "Wind" is the vector remaining, after aircraft heading is compared with the actual course followed.

ASDAR temperatures are obtained in digital form from the Flight Data Acquisition Unit (FDAU). Temperatures are sensed by a platinum wire probe mounted outside the fuselage near the aircraft's nose. The electrical resistance of the probe (which varies with temperature) is sensed on B-747s by the Central Air Data Computer, which converts resistance-value to an analog value of temperature, while also compensating for the heating-effect of rapid motion of the probe through the atmosphere. Output of the CADC is digitized by the FDAU. This value is then ready for digital recording or for use by the ASDAR unit.

As designed by NASA engineers, the FGGE ASDAR unit can be set for data collection rates varying between eight samples per hour (112 km apart), and 128 samples per hour (7.0 km between data points). For deployment in FGGE, all units were set for the slowest data collection rate, except the Air Force C-141. Its faster data collection rate (16 samples per hour), permitted tests related to flight tracking, and possible use of an ASDAR-type system to speed aircraft location in event of aircraft ditching at sea. The normal FGGE operating mode was to take eight samples per hour and transmit these as a group once per hour.

4. OPERATIONAL DEPLOYMENT

The first ASDAR test flight, on February 4, 1977, and Pan Am's routine flights in the weeks that followed demonstrated the success of the ASDAR design as a data collection platform. What remained, in addition to providing data for FGGE, was to show the success of ASDAR as a data collection system worth its cost in the world of operational meteorology. This latter step entailed flights of ASDAR units in many test environments, in sufficient quantities to permit an evaluation of ASDAR as a source of upper air data from remote regions not otherwise reported. Toward this goal, the focus of the program turned to increasing the number of operational ASDAR units (eventually 17), and deploying them in as many different operational situations as possible. Figure 1 shows the number

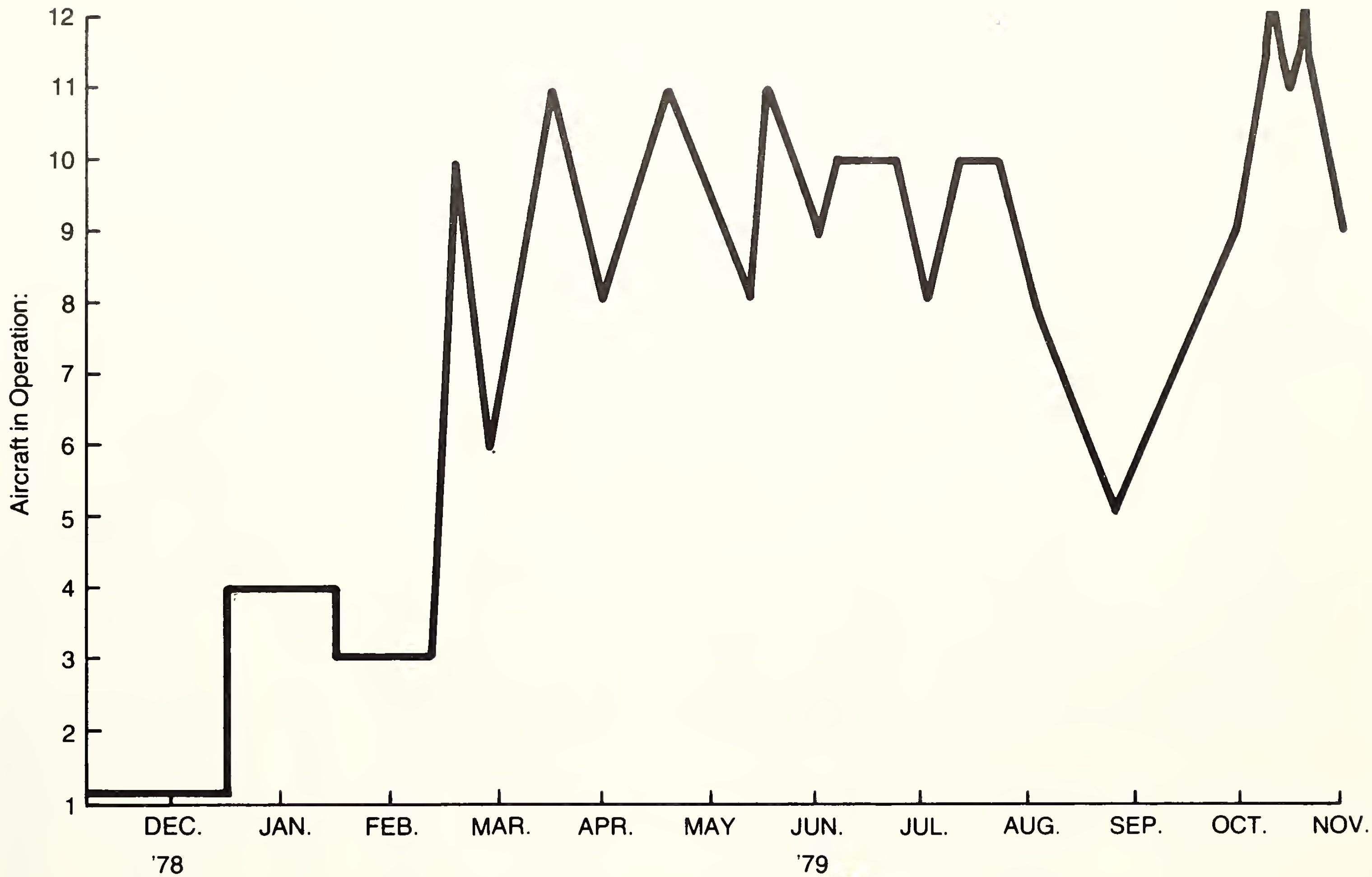

Figure 1.--Operational ASDAR fleet - FGGE.

of operating ASDAR equipped aircraft as a function of time during the FGGE Operational Year.

The ultimate FGGE ASDAR fleet proved to have remarkable diversity. Home bases ranged from Copenhagen to Sydney (Australia). Typical daily routes (Figure 2) traversed almost every major ocean and continent except South America and its adjacent oceans, and some 30,000 hourly ASDAR reports were logged,yielding 240,000 data points to the FGGE data base. During FGGE the ASDAR data were available around the world via the Global Telecommunications System (see Figure 3).

5. PROBLEMS ENCOUNTERED

5.1 FGGE ASDAR aircraft, while all B-747s, were found to have large differences in the kinds of avionics to which ASDAR would interface. Indeed, in two instances a "standard" interface for ASDAR had to be installed in addition to the aircraft's own processor-boxes for altitude and temperature, in order to permit reporting of these parameters by ASDAR.

5.2 A finite budget for ASDAR during FGGE led to some compromises. No changes were permitted to be made in the flight hardware without the approval of FAA safety inspectors. In some instances proposed modifications were dropped, because they could be approved only after additional flight tests to demonstrate that the package remained safe for commercial use. For a B-747, flight test time cost $14,000/ hour. Other surprises were related to the differences found within B-747s, and between B-747s and DC-10s. The latter might have been accommodated by changes made within ASDAR units. However, with those changes, new flight tests for safety would have been required. These proved too costly for the FGGE budget for ASDAR. DC-10s were not used, as a result.

5.3 Deployment on foreign airlines showed the need for extensive documentation of the initial tests for the ASDAR units. In many instances, safety tests were repeated in other countries, to supplement information supplied from the U.S. ASDAR manufacturer.

5.4 Shipment of failed units back to NASA for repair proved far more costly and slower than was anticipated. This lesson tends to confirm an early suspicion that repair depots located at several spots around the globe might prove cost effective in a test program such as ASDAR. For an operational program, airlines would themselves undertake many repairs, and would subsidize shipping of failed units. The costs to local weather services and to NOAA and NASA would then remain far less than was true in the FGGE deployment.

6. SUMMARY

6.1 The ASDAR program was a good example of the development of useful hardware for environmental sensing, carried out under the umbrella of a large research program. ASDAR's contribution to FGGE, despite the program's modest size, was extremely important. ASDAR and its counterpart, Aircraft Integrated Data System (AIDS), which utilize on-board tape recordings of meteorological reports, were major suppliers of new upper air data. They played a key role in filling data gaps in remote areas.

6.2 By the end of the Global Weather Experiment, endorsements for ASDAR were proffered by three operational forecasting centers within the U.S., and by several major weather service centers abroad. However, the full potential of ASDAR messages, from an operational ASDAR fleet, can be realized only with modifications to the present system for delivery of weather products to aviation. More timely analyses are needed, at daily times keyed to the needs of the aviation industry.

6.3 While ASDAR reports are intended primarily for meteorological uses, they also proved of interest to planners for air safety programs. ASDAR reports permit flight-following, and, in event of an over-water accident, would more closely pinpoint areas for rescue searches than is possible with the current mandatory voice-radioed position reports. It appears likely that ASDAR will lead to more automated position reporting from aircraft, whether or not the ASDAR system is continued.

6.4 Now that FGGE operations have terminated, ASDAR remains. The system has a potential for fuel savings to airlines of perhaps $100 million a year or more, if fully exploited for improved flight level forecasts and aircraft flight track planning. Through FGGE, ASDAR has answered the pleas of forecasters, heard for many years, that commercial aviation provide data from regions where costs or location will not permit the construction of additional surface weather stations.

Table 1.--ASDAR development: Chronology

<u>1975</u>	
(January) -	NASA and NOAA agree on a plan to develop ASDAR as an operational data system, using satellite data relay, for initial test in FGGE
(May) -	NASA's Lewis Research Center, Cleveland, begins ASDAR development program. Staff, approximately 15 persons
(September) -	First ASDAR specifications proposed by Lewis Research Center
<u>1976</u>	
(March) -	Pre-FGGE testing of ASDAR to be scheduled through U.S. Domestic GOES Channel 91, pending operational status of "International Data Collection System" channels
(September) -	NOAA-NASA team solicits participation from international airlines in ASDAR program
(October) -	Lewis Research Center begins C-47 tests of ASDAR unit
(November) -	NMC begins programming for use of ASDAR transmissions
<u>1977</u>	
(January) -	ASDAR transmissions from Pan Am's "Clipper Arctic" successfully received by satellite while on the ground at JFK Airport, New York
(February) -	Australia and Sweden agree to carry ASDARs; Australia decides to buy several
(March) -	Initial antenna design proves unserviceable. Manufacturer begins again
(April) -	ASDAR broadcasts from PAA heard from beyond the geometric horizon
(April) -	Shift of ASDAR units to International DCS Channel 17 (= U.S. Channel 234) begins
(June) -	ASDAR messages sent out over the GTS
(September) -	Contract signed for commercial fabrication of additional ASDAR units

(November) - ASDAR tested via International DCS Channel 17

1978

(January) - ASDAR now reporting via two satellites, GOES East and West

(January) - First installation kit completed

(February) - ASDAR unit shipped to QANTAS

(March) - KLM's first flight, JFK to Amsterdam, tracked to 3°29'N, 50°31.7'E

(March) - ESA reports first ASDAR relay

(July) - ASDAR operational aboard USAF C-141

(August) - SAS's ASDAR installed, operational

(October) - First relay of ASDAR reports by Japanese satellite

1978

(December 1) - FGGE begins

(December 4) - USAF-(II) installed

(December 10) - QANTAS (QF7) installed

1979

(January 12) - QANTAS (8) installed

(January 19) - QANTAS (10) installed

(February 26) - Lufthansa ASDAR installed

(March 13) - Singapore (13) installed by NASA team

(March 14) - Singapore (14) installed

(March 17) - Singapore (15) installed

(April 8) - QANTAS (9) installed

(April 14) - British Airways (16) installed

(May 5) - South Africa (18) installed

(Mary 24) - British Airways (17) installed

(June 22) - South Africa (19) installed

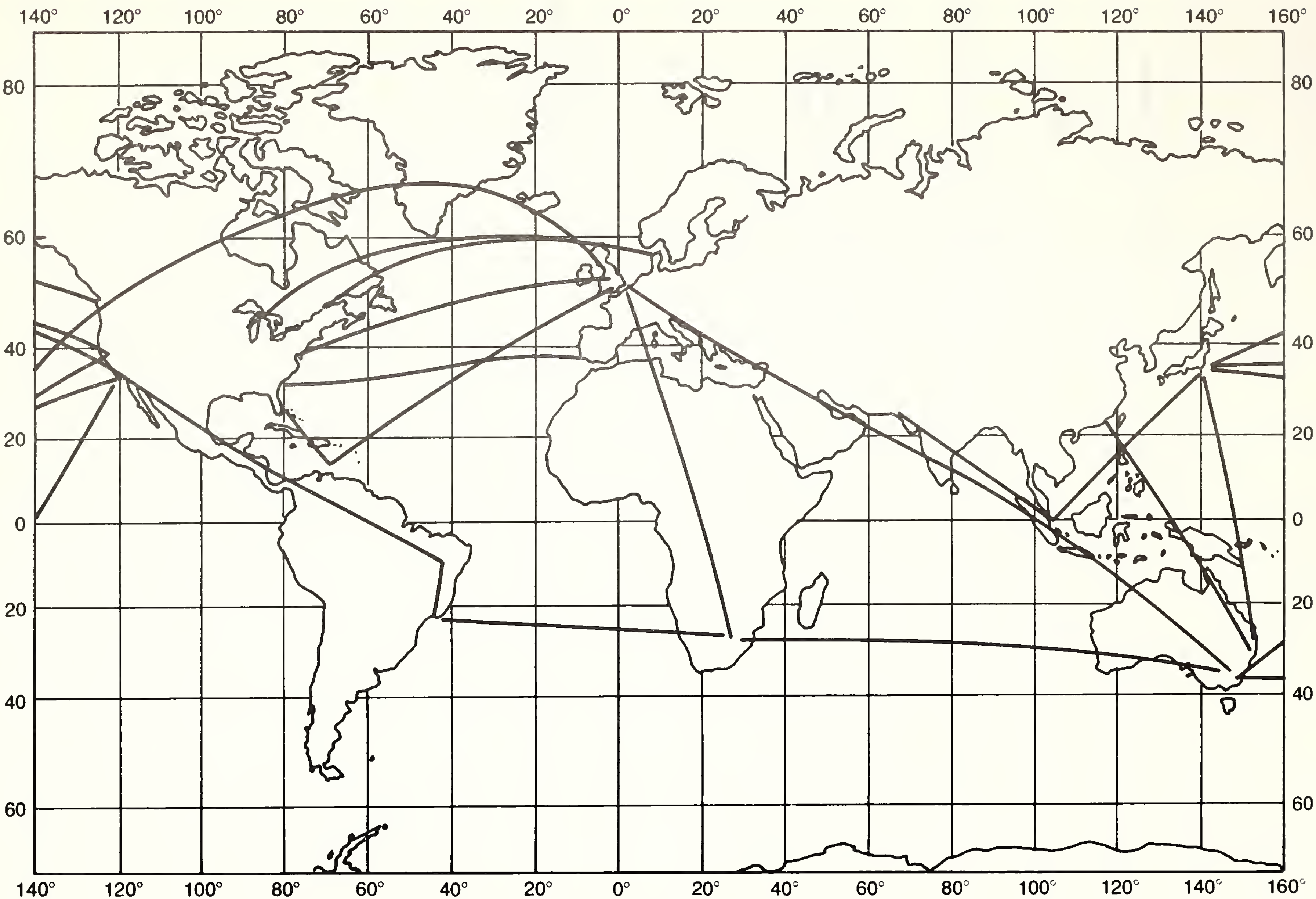

Figure 2.--Typical daily ASDAR routes covered in FGGE.

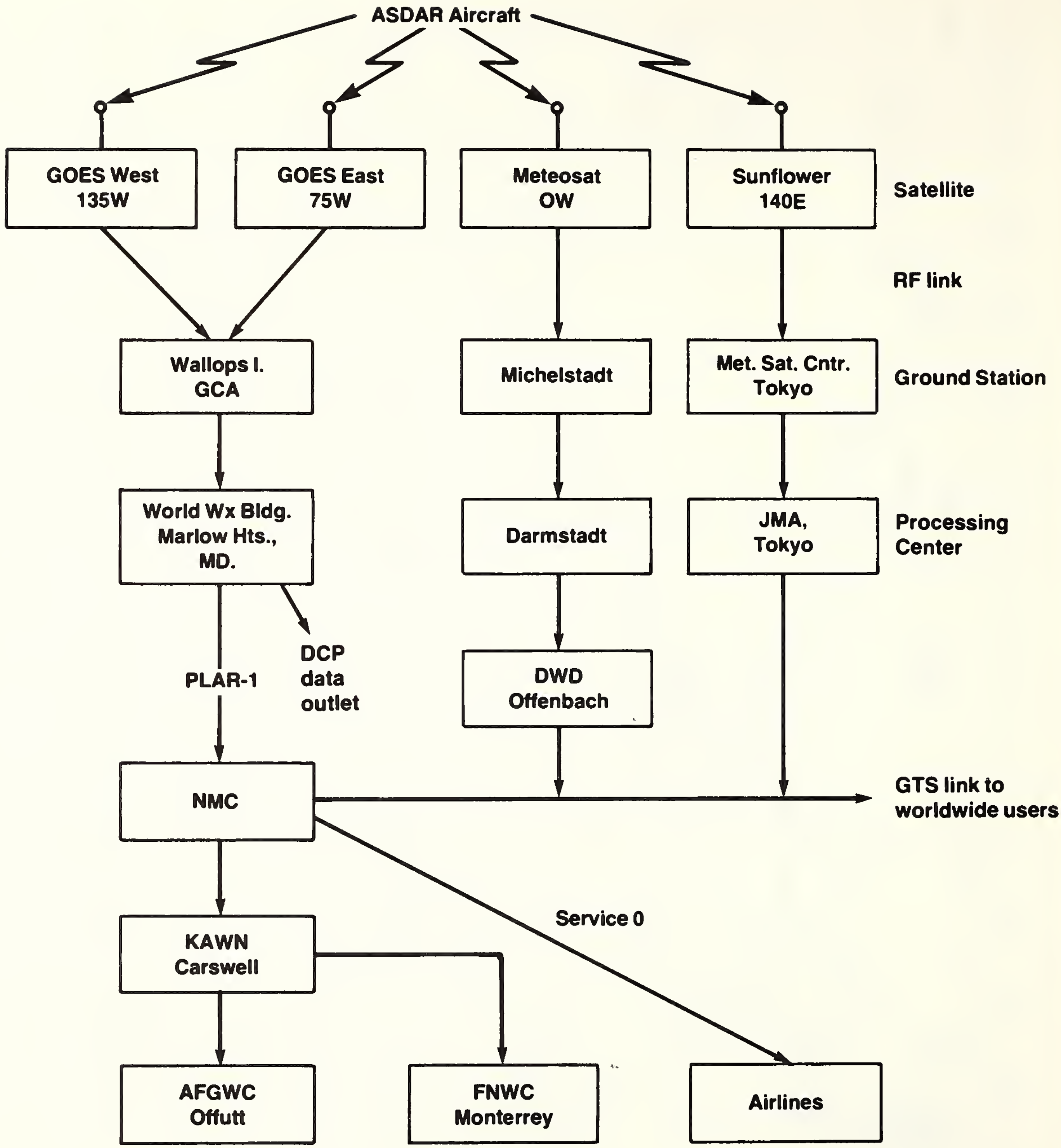

Figure 3.--ASDAR data flow, during the FGGE.

CHAPTER 10

AUGMENTATION OF THE WORLD WEATHER WATCH (U.S. PARTICIPATION)

By
Terry Bryan (NOAA)

1. INTRODUCTION

The operational surface and space-based components of the existing World Weather Watch (WWW) Global Observing System (GOS) were the primary source of observational data for FGGE - The Global Weather Experiment. However, there were serious data gaps in this network, particularly in the tropics and Southern Hemisphere where many stations were not implemented or were conducting only partial programs and where vast oceanic areas exist. The Congress of the World Meteorological Organization (WMO) appealed to Members to maximize implementation of WWW stations in these areas prior to FGGE, and the Intergovernmental Panel on FGGE recommended that those stations for which permanent installations were not planned or were difficult to implement should, as a minimum, be considered for temporary installation during the Special Observing Periods (SOPs). Several of these stations were identified as "indispensable" to FGGE.

In response to these requests for the improvement of the surface-based WWW, the United States temporarily implemented five new stations, and augmented seven existing stations in U.S. territorial areas and at locations operated by the U.S., and provided assistance to 30 upper air stations through the Voluntary Assistance Program (VAP).

2. STATIONS AND OBSERVING SCHEDULE

2.1 Temporary Implementation of New Stations

Rawinsonde observing stations were temporarily implemented for FGGE - The Global Weather Experiment at the locations listed below. These stations operated from 5 January to 5 March 1979 (SOP-I), and from 1 May to 30 June 1979 (SOP-II). Rawinsonde and surface synoptic observations were scheduled each day at 0000Z and 1200Z.

Station	Index Number	Latitude	Longitude	Type of Equipment
Enewetak	91250	11 21N	162 21E	AN/GMD-1
Woleai	91317	07 23N	143 55E	AN/GMD-2
Kapingamarangi	91434	01 05N	154 46E	AN/GMD-2
*Fanning	91487	03 54N	159 23W	AN/GMD-1
Canton	91700	02 46S	171 43W	AN/GMD-1

*Fanning had been temporarily implemented for NORPAX on a one per day, six day per week schedule. It continued temporary operations for FGGE with augmentation to two per day, seven days per week during the SOPs.

2.2 Schedule Augmentation of Existing Stations

The following existing upper air stations augmented their schedule of observations to provide two rawinsonde observations per day for the Special Observing Periods (SOP) indicated above.

Station	Index Number	Latitude	Longitude	Type of Equipment
Ascension	61902	07 58S	14 24W	AN/GMD-4
Diego Garcia	61967	07 21S	72 29E	AN/GMD-1
Truk	91334	07 28N	151 51E	AN/GMD-1
Ponape	91348	06 58N	158 13E	AN/GMD-1
Majuro	91376	07 05N	171 23E	AN/GMD-1
Koror	91408	07 20N	134 29E	AN/GMD-1
Yap	91413	09 29N	138 05E	AN/GMD-1

3. OBSERVING SYSTEM

3.1 Description

The observing systems for these locations consisted of AN/GMD rawinsonde systems which include a balloon-borne radiosonde (1680 MHz), rawin set AN/GMD, and a radiosonde recorder. By use of appropriate evaluation methods, the observer computed values of pressure, temperature, relative humidity, and wind speed and direction.

3.2 Expected Accuracy

The present standard of accuracy for the AN/GMD ( ) rawinsonde system is:

Temperature: $\pm$ 1°C
Relative Humidity: $\pm$ 5% within the temperature range of +40°C to -40°C and a relative humidity range of 10% to 100%
Pressure: $\pm$ 2mb within a range of 1050mb to 5mb
Wind Direction: $\pm$ 5°
Wind Speed:
(a) AN/GMD-1:

Mean wind vector from surface ($\pm$)

Altitude	5-30 Kts	30-60 Kts	60-90 Kts
10,000 ft	$\pm$ 2 kts	5 kts	10 kts
20,000 ft	3 kts	7 kts	15 kts
40,000 ft	4 kts	14 kts	30 kts
60,000 ft	6 kts	21 kts	*
80,000 ft	8 kts	28 kts	*
100,000 ft	10 kts	*	*

* beyond capability of equipment

(b) AN/GMD-2-4: $\pm$ 5 kts

4. OBSERVATIONAL ACCOMPLISHMENTS

The temporary and augmented stations listed in the previous section made 908 extra upper air observations for FGGE during SOP-1 and 1022 extra

observations during SOP-II. Planned and accomplished observations are listed for individual stations in Table 1.

It should be noted that these observations were made under difficult conditions in extremely remote locations. The overall figure of successfully making 92% of all planned observations is an impressive testimony to the hard work and professionalism exhibited by the involved personnel.

Examples of specific problems encountered are:

o On Enewetak only two observations were made during SOP-I before Typhoon Alice struck, knocking out power. The GMD main cable was severed in three places by flying debris. Eleven observations were missed before repairs were made and operations resumed on 11 January.

o On Canton Island, SOP-I observations commenced three days late due to last minute site and equipment problems. An additional fifteen observations were missed during the remainder of the SOP due primarily to flight and/or ground equipment failure caused by the torrential rains which occurred almost continuously.

o Woleai SOP-I operations were terminated on February 4 due to the failure of two generators and the absence of logistical replacement/repair support due to mechanical problems on the re-supply ship.

4.1 U.S. VAP Support to WWW Upper Air Network

New windfinding radars (equipment, installation, training and expendables).

82022	Boa Vista, Brazil (in cooperation with VAP-F)
82825	Porto Velho, Brazil
84008	*San Cristobal (Galapagos), Ecuador
64500	*Libreville, Gabon
97723	Ambon, Indonesia (in cooperation with VAP-F, France)
97900	Saumlaki, Indonesia
65660	Roberts Field, Liberia
61415	*Nouadhibou, Mauritania
78741	Managua, Nicaragua
98753	Davao, Philippines
63832	*Tabora, Tanzania
65503	*Ouagadougou, Upper Volta
43395	Male, Maldives
91800	Penrhyn, Cook Islands
94910	Douala, Cameroon

Radiosonde/radiowind equipment (equipment, installation, training and expendables)

78073	Nassau, Bahamas
80222	*Bogota, Colombia

TABLE 1. Summary of Additional Upper Air Observations Arranged for and Funded by the U.S. FGGE Project

STATION	SOP I ADD OBS PLANNED	SOP I OBS MADE	SOP I %	SOP II ADD OBS PLANNED	SOP II OBS MADE	SOP II %	TOTAL ADD OBS PLANNED	TOTAL OBS MADE	TOTAL %
Enewetak 91250	120	108	92	122	116	95	242	224	93
Woleai 91317	120	57*	48	122	120	98	242	177	73
Kapingamarangi 91434	120	103	86	122	120	98	242	223	92
Canton 91700	120	99	82	122	109	89	242	208	86
Total	480	367	76	488	465	95	968	832	86
Truk 91334	60	60	100	61	61	100	121	121	100
Ponape 91348	60	60	100	61	61	100	121	121	100
Majuro 91376	60	60	100	61	61	100	121	121	100
Koror 91408	60	60	100	61	61	100	121	121	100
Yap 91413	60	60	100	61	61	100	121	121	100
Total	300	300	100	305	305	100	605	605	100
Ascension 61902	78	77	99	78	78	100	156	155	99
Diego Garcia 61967	60	51	85	61	60	98	121	111	92
Total	138	128	93	139	138	99	277	266	96
Fanning 91487	120	113	94	122	114	93	242	227	94
Between SOP's							56	51	91
Total							298	278	93
TOTAL	1038	908	87	1054	1022	97	2148	1981	92

* Woleai SOP-I operations terminated 4 February due to generator failure

78720 *Tegucigalpa, Honduras
76612 Guadalajara, Mexico

*U.S. VAP support for these stations constituted improvement to existing station.

Expendables

85201 El Alto, Bolivia
85469 Isla de Pascua, Chile
85934 Punta Arenas, Chile
78762 San Jose, Costa Rica
84203 Guayaquil, Ecuador
65418 Tamale, Ghana
78641 Guatemala, Guatemala
76723 Isla Socorro, Mexico
76654 Manzanillo, Mexico
86218 Asuncion, Paraguay
84377 Iquitos, Peru

5. PARTICIPATING AGENCIES AND RESOURCES

The resources made available by the agencies participating in the temporary implementation and schedule augmentation of U.S. rawinsonde stations for the FGGE - The Global Weather Experiment are listed below.

5.1 Department of Commerce through NOAA provided:

- o Funding for equipment, material, supplies, and services over and above those normally available in support of the missions of the participating agencies.
- o Overall coordination
- o Data Management
- o Augmented observing programs at Koror, Yap, Truk, Ponape, and Majuro
- o Liaison with the Government of the Trust Territory of the Pacific Islands (TTPI)
- o Acquisition and disposition of expendables
- o Arrangements for staging at Hawaii and Guam
- o Entry of the data on the GTS
- o Technical arrangements for VAP implementation

5.2 Department of Defense through the following organizational elements provided:

Defense Nuclear Agency
Base support and logistics for operations at Enewetak Atoll

Department of the Air Force
- o Personnel, scientific equipment, and base support material for Woleai and Kapingamarangi
- o Base support and logistics for operations at Canton Island
- o Augmented observing program at Ascension Island

Department of the Army
Personnel and scientific equipment for Canton and Enewetak

Department of the Navy
- o Augmented observing program at Diego Garcia
- o Staging facilities at Guam

5.3 Department of the Interior through the Government of the Trust Territory of the Pacific Islands (TTPI) provided:

- o Land easement at Woleai and Kapingamarangi
- o Communications in the TTPI
- o A vessel for logistical support to Woleai and Kapingamarangi
- o Personnel to augment observing programs at existing stations in the TTPI

5.4 National Science Foundation

Funding for augmenting the observing program on Fanning Island

6. DATA MANAGEMENT

All upper air soundings were reduced at the station and put in the TEMP Code Form and surface observations were in the SYNOP Code Form (WMO No. 306 - Manual on Codes). Reduction techniques and procedures were in accordance with the standard operating procedures of the operating unit.

It was intended that all data would be entered on the Global Telecommunications System (GTS) for worldwide distribution. These data would thus be received at the World Meteorological Center within hours of the observation time and used for operational purposes. All data available via the GTS became a part of the FGGE data set. Most data were received in real time except from Woleai and Kapingamarangi which experienced communications problems.

Although most of the data collected during FGGE were received at the World Meteorological Center, a substantial part of the meteorological information required for the FGGE was not received before the operational cut-off time. In order to ensure that all possible data were included in the FGGE research data set, a system for collecting late data and merging them with the real-time data had been established.

At existing stations all records for the additional soundings were disposed according to the normal procedures. This ensured the inclusion of the new data into the FGGE data set.

At the new stations the following records were mailed to the National Climatic Center: Recorder Record; Calibration Chart; Data Printer Sheets; MF-3-31A, 31B, 31C; MF-5-20; and MF-1-10.

7. CONCLUSION

During FGGE the feasibility and benefits of establishing upper air stations on remote islands, at least on a temporary basis, was demonstrated. It should be noted, however, that several changes have occurred since FGGE which would have a bearing on conducting similar programs in the future.

- The Defense Nuclear Agency has terminated its clean-up operations at Enewetak and the atoll has been resettled by the indigenous population. Thus, the base support available during FGGE no longer exists.

- The Marshall and Caroline Islands which includes Enewetak, Woleai, Kapingamarangi, Majuro, Truk, Ponape, and Yap have federated and will become independent of the U.S. with the exception of defense. The Palau Islands, including Koror, will also become independent under similar terms. The U.S. National Weather Service will continue to maintain existing observations in these countries under an agreement similar to the agreement with the Government of the Trust Territory of the Pacific Islands.

- The U.S. no longer maintains any facilities at Canton Island; therefore, base support is unavailable. The newly independent country of Kiribati (formerly the Gilbert Islands) now has claim to Canton Island.

CHAPTER 11

DATA MANAGEMENT OVERVIEW

By
J. Harrison
(U.S. FGGE Project Office)

1. INTRODUCTION

The wide range of observing and data processing systems associated with the First GARP Global Experiment (FGGE) - the Global Weather Experiment, has produced an enormous amount of data. The management of these data and the creation of data products for the Global Weather Experiment have presented formidable tasks for the data management system established for the experiment. Each of the components of the data management system, international and U.S., has contributed significantly to the success of the experiment.

Detailed descriptions of the experiences and knowledge gained by each of the FGGE data producers and data centers have been accumulated by the World Meteorological Organization (WMO) Secretariat, for publication in a single document. In this chapter a brief overview of the operations of U.S. data management components is presented, followed by a description of some of the essentials of the data management scheme used for FGGE, and conclusions and recommendations drawn from the combined experiences of the participants.

2. U.S. DATA MANAGEMENT COMPONENTS

The United States has participated extensively in the production of operational and research data sets for the Global Weather Experiment, and in the subsequent archiving and distribution of the data sets. Specific areas of U.S. involvement in FGGE data management are identified below.

2.1 NMC Washington

As part of its routine operations, the National Meteorological Center (NMC) collected and processed all available observed and derived data required to support its operations. Observational data and analysis data sets were produced for the entire FGGE data collection period, January 1, 1978 to November 30, 1979. The observational data included conventional surface and upper air observations, mobile ship reports and aircraft reports collected from the Global Telecommunications System (GTS), and satellite-derived soundings and winds. The data cutoff time was around 10 hours after the nominal observation time.

The analysis data set included geopotential heights, temperatures, u- and v wind components at 12 pressure levels, relative humidity at 6 pressure levels, sea level pressure, and tropopause pressure and temperature, two times per day. It also included a snow cover field, and a sea surface temperature analysis that was generated by the National Environmental Satellite Service (NESS) from satellite derived observations. Each field was provided on hemispheric 2.5°x2.5° latitude/longitude grids.

Three magnetic tapes containing observational data and one tape containing analyses were sent to the National Climatic Center (NCC) every week. Inventories of the observational data were prepared by the NCC, and included in the archives. On an approximately monthly basis, inventories of the observational data, and magnetic tapes containing analyses, were sent to the World Data Center-B in the U.S.S.R.

2.2 U.S. Area Sub-Center

The magnitude of the task of putting together the most complete set of World Weather Watch Global Observing System (WWW GOS) surface-based data possible during the FGGE data collection period from January 1, 1978, to November 30, 1979, was so great that it was necessary to obtain the cooperation of a number of sub-centers to produce the data set. Four area sub-centers were identified for this purpose, and a surface-based data center was established with responsibilities for consolidating the area sub-center data sets into a unique set of surface-based data for the entire globe.

Specifically, the U.S. Area Sub-Center was responsible for acquiring land surface and upper air reports from its unique list of observing stations. The list included stations in WMO Regions III and IV, parts of Antarctica, and U.S. stations in Regions I and V. In the case of mobile ship and aircraft reports, the area sub-center collected and processed all available reports.

The U.S. Area Sub-Center operation was a combined effort of three NOAA elements: National Weather Service Communications Division (NWS COMMS), NMC, and NCC. NWS COMMS was responsible for real-time and non-real-time monitoring functions, NMC was responsible for near-real-time data collection and processing, and NCC was responsible for delayed collection and processing and the subsequent delivery of data tapes to the U.S.S.R. Surface-Based Data Center.

Two tapes were sent to the U.S.S.R. for each 10 days of data. The average daily number of land surface reports was around 2450. For upper air, mobile ship, and aircraft reports the average daily numbers were 450, 3800, and 2950, respectively.

2.3 U.S. Operational Satellite Data Producer

The U.S. Operational Satellite Data Producer function was carried out by NESS. Observations of sea surface temperature (SST), cloud motion vectors, and vertical temperature and moisture soundings were derived for the FGGE research data set from data obtained by U.S. operational polar-orbiting and geostationary satellites.

Cloud motion vectors were produced from the GOES-East and GOES-West satellites each day at 0000, 1200, and 1800 GMT for the entire FGGE data collection period from January 1, 1978, to November 30, 1979. Approximately 1,400 satellite cloud motion vectors were produced each day at a resolution of 250-500 km.

Sea surface temperatures from NOAA-5 were obtained from January 1 to December 31, 1978. The initial computational method for deriving sea surface temperatures from NOAA-5 Scanning Radiometer (SR) data, with atmospheric attenuation corrections from Vertical Temperature Profile Radiometer (VTPR) data, resulted in nearly 10,000 observations (4,000 of highest quality) per day, with a horizontal resolution of around 100 km. On March 16,

1978, an equipment malfunction on NOAA-5 stopped the flow of SR data, and a backup technique which used only VTPR data was quickly placed into the SST derivation operations. The quantity of SST's dropped to 4,000-5,000 observations per day, but the accuracy remained comparable to the SR method. Processing was handled in this manner until December 31, 1978.

TIROS-N sea surface temperatures, derived from Advanced Very High Resolution Radiometer (AVHRR) data, were supplied from January 3 to November 30, 1979. The number of highest quality observations increased to approximately 30,000-50,000 per day, with a horizontal resolution of around 50 km.

Two different satellite systems provided data for the derivation of clear radiances and atmospheric profiles during FGGE: the VTPR instrument on NOAA-5 and the TIROS-N Operations Vertical Sounder (TOVS) instruments on TIROS-N and NOAA-6. NOAA-5 VTPR vertical temperature profiles and clear radiances were produced from January 1, 1978, to February 28, 1979. The average daily number of clear radiance retrievals was 1300-1400, and approximately 900-1000 temperature profiles per day were processed from the clear radiance retrievals. Horizontal spacing was approximately 500 km.

TIROS-N TOVS temperature and moisture profiles and clear radiances were produced from January 1, 1979 - November 30, 1979. The average daily number of clear radiance and atmospheric profile observations was about 7,500, with a horizontal spacing of 250 km. With the operational use of NOAA-6 TOVS data on October 16, 1979, the daily total doubled to 15,000.

A normal, monthly shipment of tapes during the Build-up Year consisted of six tapes: One tape each of cloud motion vectors and sea-surface temperatures and two tapes each of clear radiances and soundings. With the start of TIROS-N operational data, one tape was produced weekly for each of sea-surface temperatures, clear radiances, and soundings; the dual TIROS-N/NOAA-6 operation raised the total to two tapes per week for both clear radiances and soundings. The tapes were sent to the Swedish Space-Based and Special Observing System Data Center.

2.4 SSEC Satellite Data Producer

The Space Science and Engineering Center (SSEC) of the University of Wisconsin, Madison, participated in the Global Weather Experiment by supporting the collection of meteorological geostationary satellite data, and processing of cloud motion vectors from these data.

The SSEC produced three types of cloud motion vectors during FGGE. The first type was a tropical high density wind set in the regions from 15°N to 15°S, utilizing two U.S. geostationary satellites. This wind set was referred to as the "Tropical wind set". The second was a macroscale wind set utilizing the full disk images from the geostationary satellite over the Indian Ocean. This data set was comparable in coverage to the cloud motion vector data set produced operationally by NESS. This data set was

referred to as the "Indian Ocean wind set". The Tropical wind set and Indian Ocean wind set were produced for the entire FGGE Operational Year from December 1, 1978 to November 30, 1979. The third type of cloud motion vectors, referred to as the "MONEX wind set" was a high density wind set using images from the geostationary satellite over the Indian Ocean; the coverage was approximately 30°N to 20°S, depending upon synoptic conditions, for a 100-day period beginning May 1, 1979. The tropical wind set was produced for 1800 GMT, the Indian Ocean set at 0000 and 1200 GMT (except when the infrared sensor failed when only 1200 GMT winds were available), and the MONEX winds at 0600 and 1800 GMT (except when the infrared sensor failed when only 0600 GMT winds were available). The average daily numbers of winds produced for the different wind sets are as follows: For the tropical wind set, the average daily number of winds was approximately 1450. For the Indian Ocean wind set, the average daily number of winds during December 1, 1978 to April 30, 1979 was approximately 1350. Because of the numerous failures of the infrared sensor between May 1, 1979 and November 30, 1979, the SSEC maximized its efforts to derive winds from visible images centered near 0900 GMT and so it is not possible to clearly separate the numbers of winds produced for the Indian Ocean and MONEX wind sets. Thus, the combined Indian Ocean wind set averaged approximately 1700 winds during the period May 1 to August 8. During the period August 9 to November 30, the average daily number of winds for the Indian Ocean wind set was approximately 1250.

Two data tapes were sent to the Swedish Space-Based and Special Observing System Data Center twice per month. The tropical wind data tape included data for half a month, and the Indian Ocean data tape included data for half a month. Data from the Indian Ocean wind set and the MONEX wind set were included on the same tape.

2.5 U.S. Experimental Satellite Data Producer

The U.S. Experimental Satellite Data Producer was operated by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), with some special processing done at the National Center for Atmospheric Research (NCAR). Plans involved providing data from the Nimbus-7 experimental satellite for incorporation into the FGGE research data set.

As of this date, the only data which have been provided are stratospheric temperature soundings from the Limb Infrared Monitoring of the Stratosphere (LIMS) instrument. Monthly shipments (one tape each month) were sent from NCAR to the Swedish Space-Based and Special Observing System Data Center, for the period December 1, 1978 to May 30, 1979. A total of 127,074 stratospheric temperature soundings were provided, averaging around 700 per day.

Additional data which will be provided for the FGGE research data sets for the entire FGGE Operational Year from December 1, 1978 to November 30, 1979, and the Nimbus-7 instruments from which the data will be derived are as follows:

- Scanning Multichannel Microwave Radiometer (SMMR)

    - sea surface temperature
    - sea surface wind speed
    - total atmospheric water vapor
    - sea ice concentration

- Solar Backscatter Ultraviolet (SBUV) instrument

    - total ozone content
    - ozone profiles

- Earth Radiation Budget (ERB) instrument

    - solar irradiance (total and spectral)
    - zonally averaged insolation
    - radiation budget parameters (longwave flux, net radiation, albedo)

These data are expected to be available during mid-1981.

2.6 Aircraft Dropwindsonde Data Center

The Aircraft Dropwindsonde Data Center was operated by NCAR. Plans involved providing dropwindsonde data obtained by aircraft operating out of staging bases in Hawaii, Panama, Mexico, Ascension Island, and Diego Garcia, during the two Special Observing Periods for FGGE.

A total of 4,328 soundings were sent from NCAR to the Swedish Space-Based and Special Observing System Data Center.

2.7 Tropical Constant Level Balloon Data Center

The Tropical Constant Level Balloon Data Center was operated by NCAR. It was established to process and provide data from the 313 super-pressure balloon systems deployed during the experiment. NCAR performed calculations on the balloon platform position and velocity data contained on data tapes received from the French Service Argos, to optimize the wind vector information contained on the data tapes.

A total of 27,498 wind vectors for the periods January 7 to March 15, 1979 and April 1 to July 16, 1979 were sent to the Swedish Space-Based and Special Observing System Data Center. These data were contained on two magnetic tapes.

Specialized Oceanographic Data Center (USA)

The Specialized Oceanographic Data Center (USA) was operated by the U.S. Navy Fleet Numerical Oceanography Center. Its purpose was to provide to the Swedish Space-Based and Special Observing System Data Center oceanographic data for the entire FGGE data collection period, January 1, 1978, to November 30, 1979. The data provided include data received in real-time over the GTS by the Specialized Oceanographic Data Center in the Federal Republic of Germany and forwarded on magnetic tapes to the Fleet Numerical Oceanography Center, data collected in real-time at the Fleet Numerical Oceanography Center over the GTS and other telecommunications circuits, and data recorded on log sheets and received by mail in non-real-time.

Each tape sent to the Swedish center contained one month of data. An average of around 3,850 oceanographic observations were provided per month.

2.9 Delayed Mobile Ship Data Collection

Under existing WMO World Weather Watch Programs, surface marine meteorological observations are recorded aboard ships participating in WMO's Voluntary Observing Ships Scheme and ships of the U.S. Navy. These observations are recorded by ships' officers in meteorological logbooks and forwarded to the National Climatic Center via respective collection centers. The standard observations, taken at synoptic times (00, 06, 12, and 18 GMT) include observations of sea surface temperature and sea and swell waves, in addition to the following surface meteorological elements: wind, visibility, present and past weather, sea-level pressure, air and dew-point temperatures, and clouds. Optional groups include ice, icing, and further cloud and wave information. These ships' data are edited and digitized by NCC on a continuing basis.

During FGGE, NCC's objective was to accelerate this program for the data period December 1978 to November 1979, and transmit the edited, digitized data to FGGE's Mobile Ship Data Center (MSDC) in Hamburg, Federal Republic of Germany. The method used for accelerating the process was to have ships mail their logs directly to NCC, rather than providing them to Port Meteorological Offices (PMO's), as they had done prior to FGGE. (In order that the Port Meteorological Offices still obtain required information about the ships, NCC prepared ships' performance reports and delivered them to the PMO's). Magnetic tapes containing the observations were prepared according to the International Maritime Meteorological Punch-Card (IMMPC) format. One tape was generated each month.

The MSDC selected data from the U.S. tapes and combined the data with those from other countries participating in the WMO Marine Climatological Summary Project. The data were then forwarded by the MSDC to the USSR Surface-Based Data Center.

The U.S. contributed 40-50% of the total number of observations coming out of the Mobile Ship Data Center. The U.S. contribution amounted to around 27,000 observations each month.

2.10 GFDL Level III-b Producer

The Geophysical Fluid Dynamics Laboratory (GFDL) is responsible for producing a daily data set of initial state parameters for the FGGE Operational Year, from December 1, 1978 to November 30, 1979. These are internally consistent data sets obtained from observational data received from the Swedish Data Center by applying four-dimensional data assimilation techniques. This process is one that transforms incomplete meteorological observations located irregularly in space and time to a regular array of complete and internally consistent meteorological data at fixed levels in time. Data sets are complete in that they specify all the model variables at all grid-point locations. They are internally consistent in that some degree of balance between wind and mass fields is accomplished by the assimilation procedure.

GFDL's planned rate of production is one observational day every two calendar days. The work at GFDL is expected to be completed in August 1982.

2.11 WDC-A for Meteorology

The primary archive for FGGE data in the U.S. is the World Data Center-A for Meteorology. Its objectives are to receive and archive FGGE data sets, to exchange data internationally, to prepare and publish appropriate catalogues, to assemble adequate documentation, and to provide copies of FGGE data to users at cost.

The WDC-A for Meteorology is operated by, and collocated with, the National Climatic Center at Asheville, North Carolina. Data for requesters are copied utilizing the NCC's facilities, and billing is handled by that center.

A WDC-A FGGE Data Catalogue has been distributed and can be obtained from the following address:

World Data Center-A for Meteorology
National Climatic Center
Federal Building
Asheville, North Carolina 28801 USA

The catalogue provides the scientific community with a list of FGGE data sets that are available at WDC-A and suggests a standard procedure to expedite acquisition of the data. The catalogue is designed in a loose leaf format so that supplements can be easily inserted to keep the catalogue current as the data are archived. The supplements are mailed at approximately three-month intervals.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Magnetic Tape Specifications and Formats

Magnetic tapes produced for international exchange for the Global Weather Experiment were required to be built in accordance with tape recording characteristics and formats approved by the WMO Commission for Basic Systems. For observational data the magnetic tapes were to be recorded at 800 BPI density, the tapes were to be 9-track tapes, and the recording code was EBCDIC. The data were to be placed on the tapes according to prescribed formats for data recording. Analyses data were to be placed on 800 BPI 9-track tapes, and recorded in binary code, according to prescribed formats.

The choice of 800 BPI density was dictated by political considerations (some countries could not read higher density tapes). Recording on magnetic tapes at 1600 BPI density is superior to 800 BPI density for economy of storage and reliability of recording purposes. Bilateral arrangements to use 1600 BPI tapes were made by some of the shipping and receiving countries. The recording density adopted as standard for tape exchanges should be kept under review to ensure optimum reliability and efficiency.

The formats used for data recording did not include specification of the originating data center in the data reports. This caused some difficulty later in dealing with the satellite data, when there was a problem with data from one satellite data producer and the data from all producers had been merged. A similar problem occurred with regard to area sub-center data, but here no indication of the method of data collection was stored. Indications of both the originating data center and the method of data collection should form part of the format used for storing data.

3.2 Checking and Correcting Data

Planning for FGGE provided that each data producer had primary responsibility for ensuring that its data products were stored on magnetic tapes according to agreed upon formats, and that the data have quality control indicators attached. Some of the data were shipped by data producers to data centers without sufficient checking of the data and formats to ensure that the exacting standards required for international exchange were met. Data producers and centers should always perform detailed evaluations of their own products according to a predetermined plan, before submitting them to another center for evaluation.

However, in spite of considerable efforts by data processing centers to develop perfect software, it is inevitable that occasional small errors of content or format will occur. Normally, the originating center should be asked to correct its software and reprocess the data set containing the errors. However, in certain cases reprocessing and redelivery of data sets by originating centers may cause considerable delays in the data production. Therefore, receiving centers should plan sufficient resources to handle and correct for such minor errors.

FGGE planning required that complete replacement tapes be sent by data producers to data receivers whenever there were errors in the data content or format that had to be corrected. This was true even though in many cases there were only a small number of errors on the tape, and they may have been contained in the same file on the tape. For greater economy and efficiency in data transfers, receiving centers should allow corrections of errors to be sent in the form of single corrected files, rather than completely rewritten tapes.

Another problem which occurred in the many FGGE data centers concerned the elimination of duplicate and near-duplicate reports. Although duplicate and near-duplicate reports were supposed to be eliminated from the FGGE data collection, efforts to do so were met with many difficulties and uncertainties, and different methods were used by the many data producers and data centers. For future efforts, a study should be made of methods of eliminating duplicate and near-duplicate reports, so that a suitable scheme can be developed in advance of the operations of the experiments.

3.3 Communications Between Centers

Planning for FGGE included exchanges of telex, cable, and GTS administrative messages as the primary communications media between data shipping and receiving centers. Initial planning required the inclusion of only the shipping or receiving date of a magnetic tape shipment, with identification of tape designators for tapes included in the shipment. Receivers of the tapes also included comments regarding readability of the tapes, descriptions of errors found on the tapes, and a statement as to whether any tapes had to be redone. Later it was found useful to include the data period contained in the shipment, and a sequence number for the message to assist in monitoring the exchange of messages between centers.

This plan for communicating between the international centers for FGGE was very successful. Most of the messages sent by U.S. data producers were sent via telex. Messages received by the U.S. were sent via telex and GTS. A number of the GTS messages did not arrive and had to be retransmitted to the U.S. Telex was far superior, but more expensive, especially for some of the non-U.S. centers.

3.4 Tracking

During FGGE it became very clear that a key ingredient to the success of each data management component was an active system for tracking the flow of information into, within, and out of the center. This was particularly noted in regard to the operations of the U.S. Area Sub-Center. In this case data which were used to produce the data set were obtained in real-time and non-real-time. The real-time received data arrived at the area sub-center on magnetic tapes from NMC and the Air Force Global Weather Central, in different formats. The non-real-time received data were sent to the area sub-center from 37 foreign countries within the area of responsibility

of the area sub-center. These mailed-in data were placed on several different kinds of forms, even though unique forms were recommended for upper air and surface reports by the area sub-center. In addition, teletype pages were also used to obtain delayed data, as were other sources of data routinely kept by the National Climatic Center.

These data had to be taken and processed using different programs into a common intermediate format. The data then had to be quality controlled and sorted, duplicates were then eliminated, and the data were then formatted to produce a final output data set. It took around 75 days to receive and prepare each shipment of data, and each shipment contained ten days of data. The operations were staggered so that at any given time data for several ten-day periods were being processed at once, each increment being in a different stage of processing.

The monitoring and tracking of input, processing, and output operations for such an effort is complex, and needs to be supported by well thought out plans and procedures. It is important that each center participating in an experiment such as FGGE, in early stages of its preparation, prepare the detailed forms and mechanisms necessary to ensure that the functions of the center are properly carried out.

While the above discussion concentrates on problems, the overwhelming result of the efforts of the eleven United States data management centers was the accomplishment of a very complex, year-long, international data exchange in an exemplary fashion.

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No. 3 The Planning of the First GARP Global Experiment - October 1969
No. 11 The First GARP Global Experiment - Objectives and Plans - March 1973
No. 18 The Monsoon Experiment (MONEX) - October 1976
No. 19 The Polar Sub-programme - March 1978
No. 21 The West African Monsoon Experiment (WAMEX) - June 1978

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No. 35 Report of the Seventh Session of WMO Executive Committee Inter-Governmental Panel on the First GARP Global Experiment - Geneva, November 1979

FGGE IMPLEMENTATION/OPERATIONS PLAN

Vol. 1 Summary of Implementation/Operations Plan

Vol. 2 Operational Direction of the FGGE and the Related Regional Experiments

Vol. 3 FGGE Data Management Plan

Vol. 4 Implementation and Operations Plan for the World Weather Watch in FGGE:
- PART A: Global Observing System
- PART B: Global Telecommunications System
- PART C: Global Data Processing System

Vol. 5 Implementation and Operations Plan for the FGGE Special Observing Systems:
- PART A: Tropical Wind Observing Ships and Other FGGE Ship Operations
- PART B: Aircraft Dropwindsonde System
- PART C: Tropical Constant Level Balloon System
- PART D: Southern Hemisphere Drifting Buoy System
- PART E: Aircraft Integrated Data System

Vol. 6 Implementation and Operations Plans for the Regional Experiments:
- PART A: MONEX - Winter
- PART B: MONEX - Summer
- PART C: WAMEX
- PART D: POLEX

Vol. 7 Oceanographic Programme for the FGGE

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APPENDIX

The following United States Government Agencies had a role in funding the Global Weather Experiment.

U.S. Department of Commerce
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U.S. Department of Energy
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U.S. Department of State
U.S. Department of Transportation
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Federal Aviation Administration, DOT
Finnish Meteorological Institute
General Electric/MATSCO
Global Associates
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Government of Argentina
Government of Australia
Government of Mexico
Government of the United Kingdom
Holmes and Narver, Inc.
Japan Meteorological Agency (Meteorological Satellite Center)
KLM Royal Dutch Airlines
Kuhne and Nagel
Lewis Research Center, NASA
Lockheed Georgia Company
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National Oceanic and Atmospheric Administration
- Data Buoy Office
- Environmental Data and Information Service
- Environmental Research Laboratories
- National Earth Satellite Service
- National Marine Fisheries Service
- National Ocean Survey
- National Weather Service
- Office of Management and Budget
- Office of the NOAA Corps

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Quanta Systems Corporation
Qantas Airlines
Scandinavian Airlines System
Service ARGOS
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University of Wisconsin, Madison (Space Science and Engineering Center)
U.S. Air Force
    Military Airlift Command
    Systems Command
    Logistics Command
    Communications Service
U.S. Army
    Electronics Research and Development Command
U.S. Bureau of Mines
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